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In reply, please refer to:  
EMD/SHW

**Risk-Based Corrective Action and Decision Making  
at Sites With Contaminated Soil and Groundwater**

TO ALL INTERESTED PARTIES:

I am pleased to present this new Hawai'i Department of Health policy on risk-based corrective action (RBCA) and decision making. This new policy provides for a rapid and relatively simple means of determining site-specific corrective action requirements for sites with contaminated soil and groundwater.

This new policy will allow for the more efficient allocation of resources devoted to the cleanup of contaminated sites by ensuring that the cleanup requirements applied to a site are appropriate for the degree of actual or potential risk posed by that site.

Please bring this policy to the attention of anyone you know who may have an interest in this matter. Should you have any questions regarding this policy, please contact either the Solid and Hazardous Waste Branch at (808) 586-4226, or the Office of Hazard Evaluation and Emergency Response at (808) 586-4249.

A handwritten signature in dark ink, appearing to read "Bruce S. Anderson".

BRUCE S. ANDERSON, Ph.D.  
Deputy Director for Environmental Health  
Hawai'i Department of Health

DEC 15 1995

\_\_\_\_\_  
Date

RISK-BASED CORRECTIVE ACTION AND DECISION MAKING AT SITES WITH  
CONTAMINATED SOIL AND GROUNDWATER

VOLUME I

December 1995  
(Revised June 1996)

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**Revisions/Updates to December 1995 RBCA manual  
as of: June 1996**

**Errata:**

**Table of Contents;** Addenda noted.

**Chapter 1, table 1-1 and 1-2, Chapter 2, Table 2-2, Appendix F, Table 1;** drinking water standard for vinyl chloride corrected.

**Chapter 1, pages 3-4;** groundwater action level discussion revised for clarity.

**Chapter 1, page 7;** text in paragraph three revised to describe Table 1-1.

**Chapter 1, page 13;** NS term defined in Table 1-1 notes.

**Chapter 2, page 17;** introduction revised for clarity.

**Chapter 2, pages 20-21;** groundwater action level discussion revised for clarity.

**Chapter 2, page 28, Appendix E, page E-1;** definition of volatile contaminant corrected.

**Chapter 2, Table 2-6, Appendix C, Table 3, Appendix E, Table 2;** molecular weight for toluene corrected.

**Chapter 2, Table 2-9, Appendix E, Table 4;** soil and particle density units corrected to  $\text{kg/m}^3$ .

**Appendix F, Table 1;** revised for clarity with respect maximum groundwater protection soil action level, SESOIL model results for benzene and toluene in Table 1d corrected.

**QUIKSOIL spreadsheet;** SAL calculation corrected to match equation in RBCA manual.

**Addenda:**

**Addendum # 1 (February 1996):** Provides additional guidance on determining the extent of soil contamination at sites and choosing soil contaminant concentrations for use in RBCA models.

**Addendum #2 (June 1996, second update):** February, 1996, version of addendum added nine contaminants to Tier 1 lookup tables. June, 1996, updates include: text revised for clarity; dioxin (2,3,7,8 TCDD), chlordane, and carbon tetrachloride added to Tier 1 lookup tables; soil action levels for Di-n-octyl phthalate corrected; groundwater action levels for 4,4 DDE corrected; molecular weight for 4,4 DDE corrected; physio-chemical constants for PCBs noted (for potential use in modeling).

**Addendum # 3 (June 1996):** RBCA manual Appendix K: Supporting Data for Tier 1 Soil Action Levels Generated Using SESOIL.

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## **ACKNOWLEDGEMENTS**

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## EXECUTIVE SUMMARY

This report presents and describes a refined, risk-based corrective action (RBCA) process that has been implemented by the Hawai'i Department of Health (DOH) for assessment and remediation of sites with contaminated soil and groundwater. Chapter 1 presents a revision of Tier 1, DOH-recommended ("default") action levels for soil and groundwater in accordance with advances made in quantitative direct-exposure and contaminant fate-and-transport models. To reflect their purpose to serve as a guide to site remedial actions but not necessarily to serve as strict "cleanup numbers", DOH has chosen to refer to the revised criteria as soil and groundwater "action" levels.

Tier 1 soil and groundwater action levels appropriate for a given site are chosen from a lookup table based on the location of the site with respect to potential impact on drinking-water resources and annual rainfall at the site. Soil and groundwater action levels for contaminants not listed in the report can be obtained from the DOH.

Groundwater action levels adhere to state and federal surface water and drinking water standards. As a minimum, groundwater action levels are set to be protective against potential adverse impact to surface water ecosystems. For sites where drinking water resources may also be impacted, groundwater action levels are refined as needed to additionally meet drinking water standards.

Soil action levels are set to be protective of direct, residential exposure to impacted soils and adverse groundwater impact due to remobilization (e.g., leaching) of contaminants from the soil. Soil action levels are generated with the aid of computer-assisted, risk-based, direct-exposure models and vadose-zone leaching models. Action levels are contaminant-specific and based on both the potential mobility and toxicity of the contaminant.

The Tier 1 soil action levels presented in the lookup table may be overly conservative for small areas of impacted soil (e.g., less than one-half acre). Chapter 2 provides guidelines for use of the models on a Tier 2, site-specific basis. In Tier 2 site assessments, DOH allows a controlled use of the Tier 1 models to generate more site-specific soil action levels without the need for a full-scale, time-consuming, and generally costly "risk assessment (Tier 3)." Site-specific factors that can be taken into account in Tier 2 assessments include the actual volume of impacted soil at the site and the geology and hydrogeology of the site. User-friendly computer spreadsheets are available from DOH for use in Tier 2 site evaluations. For further guidance on Tier 2 procedures refer Chapter 2 of this document. DOH should be consulted prior to a facility undertaking a full-scale (Tier 3) risk assessment.

## **CHAPTER 1**

### **TIER 1 ACTION LEVELS FOR SOIL AND GROUNDWATER**

#### **INTRODUCTION**

Revised Tier 1 soil and groundwater action levels are presented in Table 1-1. These criteria replace and take precedence over the criteria presented in the DOH "Technical Guidance Manual (TGM) for Underground Storage Tank Closure and Release Response (August, 1992)" (HIDOH, 1992). Tier 1 action levels applicable to a given site are determined with respect to two site characteristics (refer to Table 1-1):

1. Utility (drinking water or non-drinking water) of groundwater impacted or potentially impacted; and
2. Annual rainfall at the site (less than or greater than 200cm/year).

Groundwater action levels for sources of drinking water sources are based on state and/or federal maximum contaminant levels (MCLs) for drinking water (Table 2). Recommended actions levels for groundwater that is not a source of drinking water are taken from the state surface water standards unless otherwise noted (Hawai'i Administrative Rules Title 11, Chapter 54).

Tier 1 soil action levels were generated to address three coinciding concerns at impacted sites (refer also to notes at end of Table 1-1):

1. Potential adverse impact on groundwater due to leaching of residual contamination from impacted soil,
2. Potential adverse impact on groundwater due to remobilization of free-phase product in impacted soils, and
3. Potential threats to human health due to direct exposure to impacted soil.

The soil action levels (SALs) are considered very conservative and adequate for any impacted site unless otherwise directed by DOH.

The potential impact of leachate and free-phase product on groundwater was evaluated by use of SESOIL, a vadose-zone, contaminant-fate-and-transport computer application. Direct-exposure concerns were evaluated by a slightly modified use of quantitative, risk-based, deterministic models used by EPA Region IX for development of "Preliminary Remediation Goals (PRGs)" (USEPA, 1995). For relatively mobile contaminants (e.g., volatile and semi-volatile organic compounds), soil action levels were generated to address each of the three concerns and then compared. The most stringent of the three action levels generated was then chosen as the action level for that impacted-site scenario. For metals and other comparatively less mobile contaminants, only the direct-exposure pathway was taken into account to generate the soil action level. DOH may require additional TCLP soil analysis for less-mobile

contaminants on a site-by-site basis.

Site investigations should be carried out in accordance with guidelines presented in the DOH "Technical Guidance Manual for Underground Storage Tank Closure and Release Response (TGM)" and subsequent updates (HIDOH, 1992, 1995a, 1995b, 1995c, 1995d). At all contaminant release sites, the extent of soil and groundwater impact should be delineated out to Tier 1 soil and groundwater action levels unless otherwise approved or directed by DOH. In cases where groundwater has been impacted by a release but groundwater contaminant levels do not exceed Tier 1 action levels, it may, however, be appropriate to investigate and assess impacted soil with respect to direct-exposure concerns only. (Item 3 above, refer to section 9 and to Appendix F, Table 3.)

## **BACKGROUND**

### **Existing Criteria**

Recommended soil and groundwater action levels employed by the DOH prior to this revision are presented in Section 5, Table 5-1 of the DOH TGM (Appendix A). As retained in this revision, groundwater action levels were based on state and federal standards for drinking water and surface water.

Soil criteria were developed to meet two major goals: 1) ensure that residual contamination in vadose zone media (soil, sediment, rock, etc.) does not create an unacceptable health risk for direct human exposure through inhalation, ingestion, and dermal contact and 2) ensure that leaching of residual contamination from the vadose zone does not lead to a negative impact on groundwater resources or on surface waters. For volatile organic compounds, soil cleanup criteria were determined by multiplying corresponding, drinking water or surface water standards by an "attenuation factor" of ten, modified after a common method employed by the U. S. Environmental Protection Agency (EPA) for disposal of contaminated media in hazardous waste landfills (refer to TGM section 5.5.2.3, Appendix A).

Since publication of the August, 1992, version of the DOH TGM numerous advances have been made in quantitative, risk-based assessment of direct exposure to contaminated soil and in the field of vadose-zone contaminant fate and transport modeling. The revised soil action levels presented in this report reflect these recent advances.

### **DOH Tiered Approach to Site Remediation**

In the past, DOH has allowed to use of site-specific risk assessments as an alternative to using the conservative, generic soil and groundwater action levels presented in the TGM. DOH has expanded this tiered approach to include a conservative but more flexible and cost-efficient method of setting site-specific soil action (cleanup) levels - Tier 2. The overall concept of the tiered approach is detailed in the ASTM document

entitled "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM, 1994)." **Note that DOH has chosen not to use the example quantitative models presented in the ASTM document.**

In Tier 1, the subject of this chapter, a facility refers to conservative, default ("generic") soil action levels provided by the DOH that can be used at any impacted site. The action levels are generated by incorporating default, conservative impacted-site and exposure assumptions into standardized, quantitative groundwater-impact and direct-exposure models used by the DOH.

In Tier 2, a facility is permitted to substitute actual site data into the same Tier 1 models and evaluate groundwater protection and direct-exposure concerns on a limited, but more site-specific basis. Procedures for generating Tier 2 soil action levels are described in Chapter 2.

In Tier 3, a facility employs alternative groundwater-impact models, direct-exposure models, and/or input parameter assumptions to evaluate an impacted site and supports all input data with a thorough and rigorous risk assessment. Procedures that should be followed in the preparation of risk assessments are outlined in the August, 1992, TGM (HIDOH, 1992) and briefly reviewed at the end of Chapter 2.

Facilities where soil and groundwater contamination exceeds Tier 1 action levels are required to initiate followup "action," whether this be remediation or exposure prevention and management to default action levels (Tier 1), limited refinement of soil action levels to reflect more site-specific data (Tier 2), or full refinement of soil action levels based on a detailed, site-specific risk assessment (Tier 3). The exposure prevention and management option is outlined in the August, 1992, TGM (HIDOH, 1992).

## **OBJECTIVES**

### **Groundwater Protection Objectives**

The importance of Hawaii's groundwater and surface water resources cannot be overemphasized. Essentially 100% of Hawaii's drinking water comes from groundwater resources. The quality of the state's inland and coastal surface waters is intricately tied to the quality of the islands groundwater and likewise plays a crucial role in the ecological and, in turn, economic health of the state.

DOH groundwater protection criteria for common contaminants of concern are given in Table 1-2. Groundwater action levels for all sites are initially set to meet surface water quality criteria. This is intended to be protective of aquatic ecosystems should contaminated groundwater migrate or otherwise be discharged into a body of surface water. The criteria presented are based on state and federal acute or, when available, chronic surface water standards. For sites where the groundwater of concern is a current or potential source of drinking water ("Drinking Water Source Threatened" in



Table 1-1), action levels are adjusted where needed to ensure that state drinking water standards or alternative drinking water criteria are additionally met. Note that drinking water standards are substituted for surface water standards where the latter have not been established (e.g., benzo(a)pyrene).

Tier 1 soil action levels are set to meet the following objectives for groundwater protection:

- 1) Water that infiltrates through the vadose zone and recharges a groundwater system that is potentially interconnected to an ecologically sensitive body of surface water must meet surface water standards (either marine or fresh water, whichever is the more stringent) at the point that it passes into the groundwater.
- 2) Water that infiltrates through the vadose zone and recharges an aquifer system that is a current or potential source of drinking water must meet both surface water and drinking water standards at the time it passes into the aquifer.
- 3) Due to the heightened threat of groundwater impact, residual contamination present in the vadose-zone should not exceed theoretical saturation levels for individual contaminants of concern. Theoretical saturation levels presented for common petroleum constituents (e.g., naphthalene) are intended to address potential mobilization of the free product mixture as a whole rather than mobilization of specific contaminants.

The delineation and utility of groundwater systems on the islands should be made in accordance with the DOH policy statement "Determination of Groundwater Utility at Leaking Underground Storage Tank Sites (HIDOH, 1995b)." For the purposes of Tier 1 (and Tier 2) site evaluations, DOH assumes that all leachate that infiltrates through the vadose zone will impact a groundwater system. It is further assumed that all groundwater systems are potentially interconnected to bodies of surface water (streams, rivers, lakes, marshes, coastal waters, etc.) and that all of these surface water bodies are ecologically important.

### **Direct-Exposure Protection Objectives**

In addition to being protective of groundwater resources, Tier 1 soil action levels are set to be protective of residential exposure to impacted soils through inhalation, ingestion, and dermal absorption. With the exception of only a few compounds, most notably benzo(a)pyrene and PCBs, direct-exposure soil action levels generated are set to meet a one-in-a-million ( $10^{-6}$ ) cancer risk for carcinogenic contaminants and a hazard quotient of "1" for non-carcinogenic contaminants. The use of alternative direct-exposure objectives and assumptions at a site must be justified and documented in a Tier 3 risk assessment that is submitted to DOH for review and approval.

## **SESOIL VADOSE-ZONE CONTAMINANT-FATE-AND-TRANSPORT MODELS**

### **SESOIL Computer Application**

The potential for residual contamination to be leached from vadose zone soils and carried downward into groundwater was modeled using the RiskPro SESOIL computer application (General Sciences Corporation, 1993, Version 1.07). An overview of the SESOIL application is presented in "The New SESOIL User's Guide (August, 1994)" published by the Wisconsin Department of Natural Resources (Hetrick et al., 1994). Excerpts from the publication are provided in Appendix B. A sensitivity analysis of SESOIL conducted by the Wisconsin Department of Natural Resources (WDNR, 1993) is included in the appendix.

SESOIL is a relatively simple and very user-friendly vadose-zone, contaminant-fate-and-transport computer application. The application allows for a monthly resolution of contaminant flux into the groundwater. In actuality, contaminant levels in leachate as it passes into groundwater could exceed the target maximum concentration levels during some portion of the month and the monthly average still fall below these target objectives. Resolution on a monthly scale is, however, the current best-available technology and, given the numerous other uncertainties involved in determining site cleanup levels, DOH feels that evaluation of groundwater impact on a month-averaged scale is adequate.

### **Impacted-Site Scenario**

The generic impacted-site scenario used in the Tier 1 SESOIL simulations is depicted in Figure 1 and described in Table 1-3. The rationale behind the parameter values chosen is discussed in Appendix C. A technical discussion regarding use of the SESOIL computer application to generate groundwater-protection soil action levels that address potential groundwater impact is provided in Appendix D. An example of a SESOIL output file is provided in Attachment 1 of Appendix D. Results of the SESOIL models that were used to generate the Tier 1 lookup table (Table 1-1) are given in Appendix F.

SESOIL simulations are relatively easy to set up and run. As described in Appendix D, however, proper interpretation of SESOIL output is not necessarily straight forward and there is ample room to draw misleading or erroneous conclusions. The user must thoroughly understand the relationship between the SESOIL model simulation and the desired soil leaching model scenario. Use of SESOIL to generate alternative soil action levels for Tier 2 purposes must follow the procedures outlined in appendices C and D unless otherwise approved or directed by DOH.

## **DIRECT-EXPOSURE MODELS**

DOH uses a standardized set of quantitative, risk-based, deterministic models to generate direct-exposure soil action levels for Tier 1 purposes. Default input parameter values used to generate direct-exposure soil action levels for Tier 1 are

noted in Table 1-4. The exposure scenario assumes long-term, residential exposure to impacted soil through ingestion, inhalation, and dermal absorption. Slightly modified versions of models used by EPA Region IX to develop their "Preliminary Remediation Goals (PRGs, USEPA, 1994b, 1995)" are used to generate direct-exposure action levels for Tier 1.

Equations used in the EPA models reflect guidance provided in the California EPA document entitled "Preliminary Endangerment Guidance Manual, January, 1994" (CAEPA, 1994). A discussion of the models is provided in Appendix E. Results of the direct-exposure models used to generate the Tier 1 lookup table (Table 1-1) are given in Appendix F.

## **DEVELOPMENT AND USE OF TIER 1 LOOKUP TABLE**

### **Development of Tier 1 Lookup Table**

The Tier 1 lookup tables presented in Table 1-1 were generated by comparing soil action levels generated for groundwater leachate impact, contaminant soil saturation, and direct-exposure impact (see Appendix F) and choosing the action level that corresponded to the impact of most concern for that particular impacted-site scenario (i.e., the most stringent action level). Maximum-allowable soil action levels are set at either the action level for direct-exposure or the SESOIL-generated, theoretical soil saturation concentration of the contaminant, whichever is more stringent. The same process of comparing soil action levels for different pathways of concern is used to generate more site-specific, Tier 2 soil action levels.

Note that the relationship between soil action levels (SAL) generated for different target leachate concentrations (CI) in the same impacted-site scenario is linear:

$$(SAL_1/CI_1) = (SAL_2/CI_2).$$

Once one soil action level has been generated, derivation of other soil action levels for the same impacted-site scenario but different groundwater protection objectives is a simple matter of factoring the generated SAL by the ratio of the target leachate concentrations:

$$SAL_2 = SAL_1 \times (CI_2/CI_1).$$

This quick and easy procedure was used to generate the soil action levels for surface water protection concerns in the Tier 1 lookup table, where applicable. (e.g. Note that the ratio between benzene SALs for surface water-protection concerns and SALs for drinking water-protection concerns is consistently 340, or the ratio of the target leachate concentrations - 1.7mg/l divided by 0.005mg/l).

The minimum soil action level presented for benzene in Table 1-1 is 0.050mg/kg, unchanged from that given in the 1992 TGM. Adhering to the Tier 1 model scenario,

however, soil action levels generated by SESOIL for impacted soils within ten meters of groundwater that is a source of drinking water were actually somewhat lower (0.005mg/kg to 0.029mg/kg, refer to Appendix F). Based on previous experience at contaminant impacted sites, however, DOH believes that the SESOIL-generated soil action levels for drinking water protection concerns are overly conservative and that the difference between the SESOIL-generated estimate and the action level currently in use is not significant enough to warrant lowering the soil action level for benzene. Note that if the model parameters were slightly adjusted (rainfall, thickness of impacted layer, chemical data - especially the input benzene biodegradation rate, etc.), a soil action level of 0.050mg/kg could be easily attained.

### **General Application of Tier 1 Soil Action Levels**

The Tier 1 SALs presented in Table 1 can be applied to sites where the zone of soil contamination is two meters thick or less and that the depth to groundwater from the base of the contaminated soil is greater than two meters. Additional modeling has suggested that the Tier 1 SALs for groundwater protection are adequately protective for sites where impacted soil is within two meters of groundwater as long as the thickness of impacted soil is one meter or less (refer to following section).

Table 1-1 is divided into release site scenarios based on the utility of groundwater impacted or potentially impacted and annual rainfall at the site. Table 1-1a presents action levels applicable to sites where annual rainfall is less than or equal to 200 cm. Table 1-1b presents actions levels for sites where annual rainfall is greater than 200 cm. Rainfall maps for each of the islands are provided in Appendix G for reference to the location of impacted sites. For more detailed rainfall information contact the Department of Land and Natural Resources or the office overseeing investigation and remediation of the subject impacted site.

Initial comparison of the SESOIL application results with limited available field data suggests that the model overestimates groundwater impact by an order of magnitude or more. For sites where the base of the impacted soil is within a few meters of groundwater, it may be more prudent to investigate groundwater quality at the site rather than rely on theoretical models.

### **Application of SALs to Soils Two Meters or Less From Groundwater**

As described, the Tier 1 soil action levels are based on the assumption that the depth to groundwater beneath the base of the impacted interval is greater than two meters and that the impacted soil is less than two meters thick. If the depth to groundwater from the base of the impacted interval is less than two meters at a site and the thickness of soil impacted is greater than two meters then DOH may require that a groundwater monitoring program be initiated in order to ensure that the Tier 1 soil action levels are adequately protective of groundwater.

## **Tier 2 Modification of SALs With Respect to Dilution of Leachate in Groundwater**

The hydrogeologic nature of groundwater systems in Hawai'i is highly variable from site to site. Adhering to the intent of Tier 1 soil action levels to be conservative and applicable to any site, as well as a desire not to add an additional layer of uncertainty to groundwater-impact model, leachate dilution and degradation in groundwater is not considered in the derivation of the Tier 1 soil action levels. In Tier 2, DOH allows for adjustment of the SESOIL-generated, Tier 1 soil action levels by use of a simple groundwater mixing model (refer to Chapter 2).

## **Application of Tier 1 Action Levels to Sites With Impacted Groundwater**

At impacted sites where the main mass of contaminant has already reached and impacted groundwater, remediation of the impacted soils should be guided in part by actual groundwater monitoring. In some cases, a groundwater investigation may indicate that impacted soil is not adversely impacting groundwater even though SESOIL-generated soil action levels are exceeded (i.e., the theoretical SALs are too conservative). If this is the case, remediation of the impacted soil should be guided by direct-exposure concerns rather than groundwater-protection concerns. Conversely, a groundwater investigation may indicate that more stringent soil cleanup levels are warranted at the site (i.e., the theoretical SALs are not conservative enough). DOH anticipates that the latter case will be the exception rather than the rule.

Groundwater contamination in excess of Tier 1 action levels may not necessarily require active remediation. When groundwater contamination in excess of Tier 1 action levels is discovered at a site, the extent and magnitude of contamination should be determined. If continued monitoring and, where appropriate, through groundwater contaminant fate-and-transport modeling suggest that the plume of contaminated groundwater is not likely to migrate offsite and adversely impact groundwater extraction wells or surface water bodies then the contaminated groundwater can be left in place and allowed to degrade naturally over time. If this cannot be demonstrated then the contaminated groundwater should be actively remediated to Tier 1 action levels. Note that conclusions drawn from the results of contaminant fate-and-transport models must be supported by follow-up groundwater monitoring.

Unless otherwise approved or directed by DOH, downgradient monitoring of the plume can be discontinued when three successive seasonal cycles (generally three successive years) of groundwater monitoring indicate that the contaminated groundwater is not likely to migrate offsite and impact groundwater extraction wells or bodies of surface water at greater than Tier 1 action levels (i.e., the plume is stabilized). Monitoring of the body of groundwater that exceeds Tier 1 action levels should, however, be continued until contaminant levels drop below the action levels for two successive seasonal cycles. At this time DOH will issue a letter that no further investigative or remedial action is required at the site. Groundwater that is discharged from the site due to construction activities, etc., prior to this time must be tested for appropriate

contaminants and adhere to discharge requirements put forth by the DOH Clean Water Branch.

## **SUMMARY**

Direct-exposure and vadose-zone, fate-and-transport models offer both regulatory agencies and facilities a valuable, scientifically-based tool to help set soil and groundwater action levels at impacted sites. As the "user friendliness" of computer applications increases, however, so does the tendency to use the applications as "black boxes" without proper evaluation of how the application actually manipulates input parameter values and the significance, if any, of the input data to the output file generated. Guidelines presented in this document should be adhered to unless otherwise directed or approved by DOH.

Theoretical soil action levels set to protect groundwater resources should not be considered absolute. A preliminary comparison of the SESOIL model results with actual field data suggests that the SESOIL-generated soil action levels are overly conservative. In some cases, particularly where groundwater has already been impacted, it may be more appropriate to initiate a groundwater monitoring program to help set soil action levels rather adhering to or relying on theoretically-derived action levels. DOH should be contacted for further guidance if a facility believes this may be the case at their site.

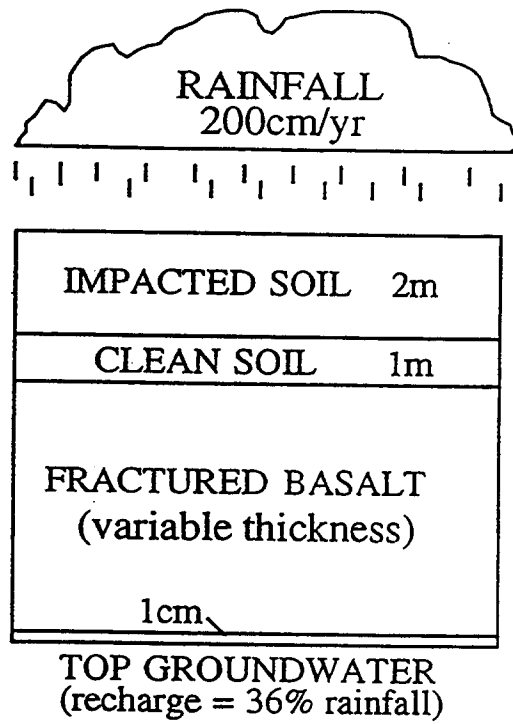


Figure 1. Geologic profile of generic model.

TABLE 1-1a.Tier 1 Action Levels for soil and groundwater: Rainfall  
≤ 200cm/year

RAINFALL ≤200CM/YEAR				
Contaminant	DRINKING WATER SOURCE THREATENED		DRINKING WATER SOURCE NOT THREATENED	
	Groundwater (mg/l)	Soil (mg/kg):	Groundwater (mg/l)	Soil (mg/kg):
Benzene	0.005	0.05	1.7	1.7
Toluene	1.0	16	2.1	34
Ethylbenzene	(0.14)	0.50	0.14	0.50
Xylene	10	23	[10]	23
Benzo(a)pyrene	0.0002	1.0de	[0.0002]	1.0de
Acenaphthene	(0.32)	18sat	0.32	18sat
Fluoranthene	(0.013)	11sat	0.013	11sat
Naphthalene	0.24	41sat	0.77	41sat
PCE	0.005	0.29	0.145	5.0de
1,1 DCE	0.046	0.47de	3.9	0.47de
Vinyl Chloride	0.002	0.18de	[0.002]	0.18de
TCE	0.005	0.01	0.70	1.5
1,1,1 TCA	0.20	0.10	6.0	3.0
PCBs (all)	0.0005	1de	0.002	1de
Lead (total)	(0.0056)	400de	0.0056	400de
Cadmium (total)	0.005	38de	0.009	38de
TPH-residual fuels	NS	5,000	NS	5,000
TPH-middle distillates	NS	5,000	NS	5,000
TPH-gasolines	NS	2,000	NS	2,000



TABLE 1-1b.Tier 1 Action Levels for soil and groundwater: Rainfall  
> 200cm/year

RAINFALL >200CM/YEAR				
Contaminant	DRINKING WATER SOURCE THREATENED		DRINKING WATER SOURCE NOT THREATENED	
	Groundwater (mg/l)	Soil (mg/kg):	Groundwater (mg/l)	Soil (mg/kg):
Benzene	0.005	0.05	1.7	0.68
Toluene	1.0	2.6	2.1	5.5
Ethylbenzene	(0.14)	0.13	0.14	0.13
Xylene	10	8	[10]	8
Benzo(a)pyrene	0.0002	1.0de	[0.0002]	1.0de
Acenaphthene	(0.32)	18sat	0.32	18sat
Fluoranthene	(0.013)	11sat	0.013	11sat
Naphthalene	0.24	41sat	0.77	41sat
PCE	0.005	0.04	0.145	1.1
1,1 DCE	0.046	0.47de	3.9	0.47de
Vinyl Chloride	0.002	0.18de	[0.002]	0.18de
TCE	0.005	0.004	0.70	0.56
1,1,1 TCA	0.20	0.06	6.0	1.9
PCBs (all)	0.0005	1de	0.002	1de
Lead (total)	(0.0056)	400de	0.0056	400de
Cadmium (total)	0.005	38de	0.009	38de
TPH-residual fuels	NS	5,000	NS	5,000
TPH-middle distillates	NS	5,000	NS	5,000
TPH-gasolines	NS	2,000	NS	2,000

TABLE 1-1 (cont.). Tier 1 Action Levels for soil and groundwater: Notes

**ANNOTATIONS:**

unmarked criteria: groundwater-protection concerns dominate  
 de: direct-exposure concerns dominate  
 sat: saturation concentration, groundwater-protection concerns dominate  
 () Same as surface water; surface water standard more stringent than drinkingwater standard.  
 [] Same as drinking water; surface water standards not set.  
 NS: no standard, no drinking water or surface water criteria set.  
 PCE: tetrachloroethylene, DCE: dichloroethylene, TCE: trichloroethylene, TCA: trichloroethane,  
 PCBs: polychlorinated biphenyls, TPH: total petroleum hydrocarbons

**NOTES:**

1. Determination of groundwater utility should be determined based on the DOH policy *Determination of Groundwater Utility at Leaking Underground Storage Tank Sites* (September 13, 1995). (HIDOH, 1995b)
2. TPH criteria as presented in *Reporting, Remediation, and Management of Petroleum-Contaminated Soil* (December, 1995). (HIDOH, 1995d). Gasolines: characterized by a predominance of alkyl benzenes and straight-chain, branched, and cyclo- alkanes and alkenes with carbon ranges of C6 to C12. Middles distillates (e.g., kerosene, diesel fuel, home heating fuel, jet fuel, etc.): characterized by a predominance of straight-chain alkanes and polynuclear aromatic hydrocarbons with carbon ranges of C12 to C24. Residual fuels: characterized by long chain alkanes (carbon range >C24) and less predominant aromatics that include phenathrenes, benzopyrenes, and other poly-nuclear aromatic hydrocarbons.
3. The facility should contact DOH for further guidance when laboratory practical quantification limits exceed the recommended groundwater criteria.
4. Lowermost limit on soil action levels for benzene leachate concerns set at 0.05mg/kg based on field experience rather than adhering to SESOIL results. (See Chapter 1.)
5. Soil action levels set for leachate-impact concerns (SALs not annotated with "sat" or "de") assume depth to groundwater is two meters or less and assume no dilution of leachate in groundwater (i.e., Dilution Attenuation Factor (DAF) = 1. Not applicable to TPH criteria. See Chapter 2 and Table 1 in Appendix F.).
6. Refer to Tier 2 discussion (Chapter 2) for guidance on adjustment of Tier 1 leachate-impact SALs with respect to depth to groundwater from the base of the impacted soil and site-specific DAFs.

**GROUNDWATER-IMPACT MODEL (see text)**

Climate data: Standard rainfall models: 'Āhuimanu Loop station data adjusted to 200cm annual rainfall.  
 High rainfall models: Honomū Mauka station data adjusted to 400cm annual rainfall.  
 Geologic model: Sand or very permeable saprolite/soil overlying fractured, porous basalt.

**DIRECT-EXPOSURE MODEL (see text)**

Assumes long-term residential exposure to impacted soil through inhalation, ingestion, and dermal absorption.

TABLE 1-2. Tier 1 and Tier 2 groundwater protection standards

Contaminant	<sup>1,2</sup> Current/Potential Drinking Water Resource (mg/l)	<sup>1,3</sup> Non-Drinking Water Resource (mg/l)
Benzene	0.005	1.7
Toluene	1.0	2.1
Ethylbenzene	(0.14)	0.14
Xylene	10	[10]
Benzo(a)pyrene	0.0002	[0.0002]
Acenaphthene	(0.32)	0.32
Fluoranthene	(0.013)	0.013
Naphthalene	<sup>5</sup> 0.24	0.77
PCE	0.005	<sup>4</sup> 0.145
1,1 DCE	0.046	3.9
Vinyl Chloride	0.002	[0.002]
TCE	0.005	0.70
1,1,1 TCA	0.20	6.0
Lead (total)	(0.0056)	<sup>4</sup> 0.0056
Cadmium	0.005	<sup>4</sup> 0.0093
PCBs	0.0005	<sup>6</sup> 0.002

() Same as surface water; surface-water standard more stringent than drinking water standard.

[] Same as drinking water; surface-water standards not set.

1. Groundwater utility as defined by DOH (refer to HIDOH, 1995b).

2. Drinking water MCL for contaminant unless otherwise noted (HAR Chapter 11-20, 1994).

3. Surface water acute standard (or chronic standard where available and applicable) for contaminant unless otherwise noted (HAR Chapter 11-54, 1992).

4. Marine chronic surface water quality standard as established in HAR, HAR 11-54.

5. Drinking water criteria provided in USEPA Region IX Preliminary Remediation Goals document (USEPA, 1995).

6. Ecology-based, freshwater acute standard used for PCBs. (Freshwater and chronic standards are based on FDA action levels for PCBs in fish for commercial consumption rather than ecological impact and were not used in this study.).

TABLE 1-3. Site parameters and default values used in Tier 1 SESOIL models

<b><u>Climate Data:</u></b>			
Air Temperature:		25°C (all months)	
Evapotranspiration (cm/day):		40% of rainfall	
Precipitation (cm/month):		200 or 400cm/year, month-specific	
Storm Duration (days)		month-specific	
Number of Storms:		month-specific	
Days per Month:		30.4 (default, all months)	
<b><u>Soil Properties:</u></b>			
Bulk Density (g/cm <sup>3</sup> ):		1.5 (all layers)	
Intrinsic Permeability (cm <sup>2</sup> ):		0 (specified in soil column input)	
Disconnectedness Index:		3.5 (all layers)	
Effective Porosity:	0.3 (all layers)		
Organic Carbon Content (%):		0.1 (layer specific)	
Cation Exchange Capacity (meq/100g):		0 (all layers)	
Freundlich Equation Exponent:		1.0 (all layers)	
<b><u>Application Data:</u></b>			
Number of years of input data:		25	
Number of geologic column layers:		4	
Application area:		1,000cm <sup>2</sup>	
Spill mode:		Instantaneous	
Pollutant input mode:		Concentration (ug/g)	
Washload Simulation:		not used	
<b><u>Soil Column Properties:</u></b>			
<u>Layer #</u>	<u>Thickness</u>	<u>Permeability</u>	<u><sup>1</sup>OC Content</u>
1 (soil)	200cm	1E-07cm <sup>2</sup>	same as input
2 (soil)	100cm	1E-07cm <sup>2</sup>	1.0
3 (basalt)	400cm	1E-06cm <sup>2</sup>	0.001
4 (basalt)	1cm	1E-06cm <sup>2</sup>	0.001
1. Foc as a fraction of the input soil property value			
<b><u>Pollutant Loading Data (Layer 1 only)</u></b>			
1st year, 1st month		Input concentration (ug/g) calibrated to specific contaminant & model	
Load for all other months		0 ug/g	
Volatilization (fraction)		0.2 (all months)	

TABLE 1-4. Exposure parameters and default values used in Tier 1 direct-exposure models

<b>Human Receptor Data</b>	<b>Default</b>
25% surface area - adults (cm <sup>2</sup> )	5000
25% surface area - children (cm <sup>2</sup> )	2000
Adherence factor (unitless)	0.2
Inhalation Rate - adults (m <sup>3</sup> /d)	20
Inhalation Rate - children (m <sup>3</sup> /d)	10
Soil ingestion rate - adults (mg/d)	100
Soil ingestion rate - children (mg/d)	200
Exposure time - residents (h/d)	24
Exposure frequency - residents (d/y)	350
Exposure duration - residents total (yrs)	30
Exposure duration - children (yrs)	6
Body weight - adult (kg)	70
Body weight - child (kg)	15
Averaging time (yrs)	70
<b>Other variables</b>	
Diffusion height (m)	2

## CHAPTER 2

### TIER 2, SITE-SPECIFIC EVALUATION OF IMPACTED SOILS

#### INTRODUCTION

The generic, Tier 1 soils action levels (SALs) presented in Chapter 1 are set to satisfy groundwater and direct-exposure objectives at sites with extensive amounts of contamination. For sites with limited contamination, however, the Tier 1 SALs may be overly stringent and lead to unnecessary cleanup actions. This chapter presents guidelines for generating more site-specific, "Tier 2" soil action levels using the same models and procedures incorporated into the development of the Tier 1 lookup tables.

The Tier 2 process allow facilities to take into account the actual volume of contaminated soil at the site, the depth to groundwater and the expected dilution of contaminant leachate as it passes into groundwater. Corresponding site-specific data that may be incorporated into the Tier 2 models include the areal extent of contamination, the thickness of the impacted soil interval, the depth to groundwater from the base of the impacted soil, the regional groundwater gradient and the annual rainfall at the site.

In accordance with objectives set forth in development of the Tier 1 SALs, Tier 2 SALs must address the following concerns:

1. Potential adverse impact on groundwater due to leaching of residual contamination from impacted soil,
2. Potential adverse impact on groundwater due to remobilization of free-phase product in impacted soils, and
3. Potential threats to human health due to direct exposure to impacted soil.

Tier 2 SALs generated to satisfy the above groundwater-protection and direct-exposure concerns are compared and the most stringent SAL (i.e., the SAL that satisfies both concerns) are applied to the site. An example is given in Table 2-1.

[Note that the groundwater action levels presented in Chapter 1 are fixed and cannot be made more "site-specific". As discussed at the end of this chapter, however, exceeding groundwater action levels at a site does not necessarily require that immediate, engineered remedial actions are necessary.]

Tier 2 SALs can be generated by use of one or more of four DOH-approved computer models and spreadsheets:

1. SESOIL (General Sciences Corporation, version 1.07 and later updates) - used to address leachate impact on groundwater and potential mobilization of free product from impacted soil;

2. QUIKSOIL (DOH spreadsheet) - used as a quick but simplistic and conservative alternative to SESOIL to address leachate impact on groundwater; (Not recommended for highly volatile or biodegradable contaminants or for sites where the base of the impacted soil is greater than ten meters from groundwater.);
3. DAF (DOH spreadsheet) - used to approximate a site-specific dilution attenuation factor (DAF) that reflects the dilution of leachate it mixes with groundwater. Tier 1 or Tier 2 SALs generated with SESOIL or Tier 2 SALs generated with QUIKSOIL should be multiplied by the site DAF to refine final SALs for groundwater-protection concerns.
4. DETIER2 (DOH spreadsheet) - used to evaluate potential impact on human health from direct-exposure to impacted soil.

The groundwater-protection models are especially applicable to sites impacted with relatively mobile organic contaminants. The SESOIL computer application is available from the noted distributor. The QUIKSOIL, DAF, and DETIER2 spreadsheets are available from the DOH Solid and Hazardous Waste Branch. SESOIL models normally take ten to thirty minutes to complete once the operator has collected the necessary input data and has become familiar with the application. Use of the application must adhere to procedures presented in this chapter unless otherwise approved or directed by DOH. Spreadsheet calculations take only a matter of minutes.

Site investigations should be carried out in accordance with guidelines presented in the DOH "Technical Guidance Manual for Underground Storage Tank Closure and Release Response (TGM)" and subsequent updates (HIDOH, 1992, 1995a, 1995b, 1995c, 1995d). At all contaminant release sites, the extent of soil and groundwater impact should be delineated out to Tier 1 soil and groundwater action levels unless otherwise approved or directed by DOH. In cases where groundwater has been impacted by a release but groundwater contaminant levels do not exceed Tier 1 action levels, it may, however, be appropriate to investigate and assess impacted soil with respect to direct-exposure concerns only. (Refer to section 9 and to Appendix F, Table 3.)

Facilities are encouraged to use the Tier 2 models to address site-specific remediation needs rather than rely on the Tier 1 lookup tables or before undertaking a more costly and time consuming "Tier 3" site evaluation. Facilities should be aware, however, that re-use and disposal of impacted soil left in place at a site may fall under regulation by the DOH Office of Solid Waste Management should that soil ever be excavated, regardless of whether the soil meets Tier 1, 2, or 3 criteria for groundwater-protection and direct-exposure concerns (refer to HIDOH, 1995d).

Section 2 and 3 of this chapter reviews DOH's tiered approach for setting appropriate soil and groundwater action levels at a site and discusses groundwater-protection and direct-exposure objectives. Sections 4, 5, 6, and 8 present models for generation of Tier 2 SALs for groundwater-protection concerns. Section 7 presents a model for

generation of Tier 2 SALs for direct-exposure concerns. Section 9 summarizes the procedure for choosing the appropriate SAL for a site and provides results from four example sites. **Readers are encouraged to briefly review the example results (Appendix I) before moving on to the main text of this chapter.**

Section 10 provides additional guidance for sites where groundwater has already been impacted by a vadose-zone release. The final section of the chapter briefly reviews the intent of Tier 3 risk assessments and introduces a Tier 3, direct-exposure spreadsheet (DETIER3) available from DOH for public use. Note that for use in this report, the term "soil" refers to any unlithified, subsurface, solid media.

## **DOH TIERED APPROACH TO SITE EVALUATIONS AND REMEDIAL ACTIONS**

In the past, DOH has allowed the use of site-specific risk assessments ("Tier 3") as an alternative to use of default, generally conservative, soil and groundwater action levels ("Tier 1"). The high costs and general lengthy review time typical associated with formal risk assessments, however, made the use of this option prohibitive at all but the largest release sites or sites where potential remedial costs outweighed risk assessment costs.

In response to this dilemma, DOH has refined its tiered approach to site remedial actions to include a conservative but more flexible and cost-efficient method of setting site-specific soil action levels - Tier 2. The overall concept of the tiered approach to site evaluations is detailed in the ASTM document entitled "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM, 1994)." (Note that DOH has chosen not to use the example quantitative models presented in the ASTM document.)

In Tier 1, a facility refers to conservative, default ("generic") soil action levels provided by the DOH that can be used at any impacted site (refer to Chapter 1). The Tier 1 action levels were generated by incorporating default, conservative impacted-site and exposure assumptions into standardized, quantitative groundwater-protection and direct-exposure models used by the DOH.

In Tier 2, the subject of this chapter, a facility is permitted to substitute actual site data into the same models used to generate Tier 1 SALs as well as additional, DOH-approved models and evaluate groundwater-protection and direct-exposure concerns on a controlled, but more site-specific basis.

In Tier 3, a facility employs alternative groundwater-impact models, direct-exposure models, and/or input parameter assumptions to evaluate an impacted site and supports all input data with a thorough and rigorous risk assessment. Procedures that should be followed for the preparation of Tier 3 risk assessments are briefly outlined at the end of this chapter and more fully discussed in DOH technical guidance manuals (HIDOH,1992).



Impacted sites with contaminant concentrations in excess Tier 1 soil or groundwater action levels required to initiate followup "action," whether this be remediation to default action levels (Tier 1), limited refinement of soil action levels to reflect more site-specific data (Tier 2), or full refinement of soil action levels based on a detailed, site-specific risk assessment (Tier 3).

## **TIER 2 SOIL ACTION LEVEL - OBJECTIVES**

### **Groundwater Protection Objectives**

The importance of Hawaii's groundwater and surface water resources cannot be overemphasized. Essentially 100% Hawaii's drinking water comes from groundwater resources. The quality of the state's inland and coastal surface waters is intricately tied to the quality of the islands groundwater and likewise plays a crucial role in the ecological and, in turn, economic health of the state.

Tier 2 soil action levels for groundwater-protection concerns must be set to meet the following objectives:

- 1) Leachate that infiltrates through the vadose zone and recharges any groundwater system must not cause the groundwater to be impacted at greater than DOH standards for surface water (either marine or fresh water, whichever is the more stringent).
- 2) Leachate that infiltrates through the vadose zone and recharges a groundwater system that is a current or potential source of drinking water must not lead to a groundwater impact that exceeds either surface water or drinking water standards.
- 3) Due to the heightened threat of groundwater impact, residual contamination present in the vadose-zone should not exceed Tier 1, theoretical saturation levels for individual contaminants of concern.

The delineation and utility of groundwater systems on the islands should be made in accordance with the DOH policy statement "Determination of Groundwater Utility at Leaking Underground Storage Tank Sites (HIDOH, 1995b)." For the purposes of both Tier 1 and Tier 2 site evaluations, DOH assumes that all leachate that infiltrates through the vadose zone will impact a groundwater system. It is further assumed that all groundwater systems are potentially interconnected to bodies of surface water (streams, rivers, lakes, marshes, coastal waters, etc.) and that all of these surface water bodies are ecologically important.

DOH groundwater action levels for common contaminants of concern are repeated in Table 2-2. As discussed in Chapter 1, groundwater action levels for any site are initially set to meet surface water quality criteria. This is intended to be protective of aquatic ecosystems should contaminated groundwater migrate or otherwise be

discharged into a body of surface water. The criteria presented are based on state and federal acute or, when available, chronic surface water standards. For sites where the groundwater of concern is a current or potential source of drinking water ("Drinking Water Source Threatened" in Table 1-1), action levels are adjusted where needed to ensure that state drinking water standards or alternative drinking water criteria are additionally met. Note that drinking water standards are substituted for surface water standards where the latter have not been established (e.g., benzo(a)pyrene).

### **Direct-Exposure Objectives**

In addition to addressing groundwater protection concerns, Tier 2 SALs ultimately applied to a site must be also be protective of residential exposure to impacted soils through inhalation, ingestion, and dermal absorption. With the exception of only a few compounds, most notably benzo(a)pyrene and PCBs, direct-exposure soil action levels generated are set to meet a one-in-a-million ( $10^{-6}$ ) cancer risk for carcinogenic contaminants and a hazard quotient of "1" for non-carcinogenic contaminants. The use of alternative direct-exposure objectives and assumptions at a site must be justified and documented in a Tier 3 risk assessment that is submitted to DOH for review and approval.

## **GENERATION OF TIER 2 SALs FOR GROUNDWATER-PROTECTION CONCERNS - SESOIL APPLICATION**

### **SESOIL Computer Application**

RiskPro's SESOIL vadose-zone contaminant fate and transport computer application (GSC, 1993, Version 1.07) developed by General Sciences Corporation (GSC) or updates to the application must be used for Tier 2 evaluations of potential groundwater impact unless otherwise approved or directed by DOH. An overview of the RiskPro SESOIL application is presented in "The New SESOIL User's Guide (August, 1994)" published by the Wisconsin Department of Natural Resources (Hetrick et al., 1994). Excerpts from the publication are provided in Appendix B. A sensitivity analysis of SESOIL conducted by the Wisconsin Department of Natural Resources (WDNR, 1993) is included in the appendix.

Other versions of the SESOIL application may be inappropriate for use in either Tier 2 or Tier 3 site evaluations. An example of unacceptable versions of SESOIL include the SESOIL module in the 1995 "Decision Support Software" computer application put forth by the American Petroleum Institute (API, 1994). Output from this version of SESOIL provides only a yearly resolution of groundwater impact, rather than monthly as in the original version of the application.

A table of SESOIL-generated SALs based on the default Tier 1 site scenario are presented in Appendix F for variable depths to groundwater. As an alternative to re-running SESOIL models at sites where depth to groundwater may be an important

factor in setting groundwater protection SALs, facilities can refer to SALs presented in Appendix F for use in Tier 2 assessments. The default SALs should be multiplied by the appropriate site dilution attenuation factor, as described below, in order to generate a final groundwater protection SAL for the site.

Unless otherwise approved or directed by DOH, use of SESOIL to generate soil action levels for Tier 2 (or Tier 3) purposes must follow assumptions and procedures described in this chapter. Note that for Tier 3 site evaluations, any vadose-zone application can be used provided that the application generates at least a monthly resolution for groundwater impact. If the model results are not as conservative as would have been produced using the GSC version of SESOIL, however, then the discrepancy should be discussed and justified in the Tier 3 report and use of the application approved by DOH.

### **SESOIL Model Procedures**

Procedures regarding use of SESOIL to generate initial Tier 2 SALs are described below. Each step corresponds to an input module of the application. Fill out and submit the SESOIL worksheet provided in Appendix D (attachment D2) for each mode run. A summary of the input data parameters and default values used in the Tier 1 models is provided in Table 2-3. A complete description and discussion of the Tier 1 default parameter values is provided in Appendix C.

#### **Step 1: Input Model Simulation Information**

Note the site name, DOH ID number, and contaminant modeled in the module heading. "Raingage station" refers to the source of climate data used in the simulation. The number of years of climate data input will normally be "1" (climate data is repeated in subsequent model simulation years). The model simulation time will vary based on the physio-chemical nature of the contaminant and the hydrogeology of the site. (Due to memory limitations, the IBM 466DX used for Tier 1 could not run SESOIL simulations greater than 25 years in length.)

#### **Step 2: Input Climate Data**

Input data from the most correlative climate station (an optional climate data set is available with the RiskPro SESOIL application). Evapotranspiration can be directly calculated from input cloud cover, humidity, and albedo data. For most climate stations, however, these data are not available. If this is the case, input a value of "0" for monthly cloud cover, humidity, and albedo data and input evapotranspiration as a fraction of total rainfall based on the island location of the site as follows (data from Atlas of Hawai'i, 1983): Ni'ihau: 72% total rainfall, Kaua'i: 24% total rainfall, O'ahu: 36% total rainfall, Moloka'i: 54% total rainfall, Maui: 27% total rainfall, Lāna'i: 66% total rainfall, Kaho'olawe: 70% total rainfall, and Hawai'i: 44% total rainfall. Note that evapotranspiration data must be input as cm/day.

Where appropriate climate data are not available, determine the annual rainfall for the site based on maps provided in Appendix G. Refer to the default climate data provided in Table 2-4 and modify the default monthly precipitation (total 200cm/year) to reflect actual annual rainfall determined for the site (e.g., for sites with 100cm of annual rainfall the default precipitation data would be multiplied by a factor of 0.5). Input evapotranspiration as the appropriate, daily fraction of total rainfall based on the island that the site is located on (see above).

### Step 3: Input Soil Property Data

Input site-specific soil property data where supported by information gained during the site investigation or related published reports. Otherwise, use the default, Tier 1 parameter values noted in Table 2-3. For sites where mixtures of contaminants are present (e.g., petroleum releases), assume that an organic carbon content of no more than 0.1% is available for sorption of any given contaminant.

The data input into the soil property module are applied to the uppermost layer of the geologic model and then used as default values for subsequent layers. Input a value of "0" for the default soil permeability. Layer-specific permeability will be set in the "Soil Column Properties" module (step 6).

The default soil property data presented in Table 2-3 are based on information published by the U.S. Department of Agriculture (Foote et al., 1972; USDOA, 1976; USDOA, 1992) and the University of Hawai'i - Mānoa Water Resources Research Center (Miller et al., 1988; Mink and Lau, 1990), and also on discussions with local experts of Hawai'i's soils and hydrogeology (Table 2-5). Refer to the discussion in Appendix C and the DOH Tier 1 document for additional discussion regarding soil and bedrock properties in Hawai'i.

### Step 4: Input Physio-Chemical Constants for Contaminant

Default physio-chemical constants and biodegradation rates for common contaminants are provided in tables 2-6 and 2-7. These constants should be used for both the SESOIL and direct-exposure models unless otherwise approved or directed by DOH. Contact the DOH Solid and Hazardous Waste Branch for information regarding contaminants not listed in the table. A value of "0" will normally be input for the hydrolysis and complexation constants noted in the module. Refer to Appendix C for a discussion on the source and justification of the default physio-chemical constants and biodegradation rates provided. Input physio-chemical constants can be supplemented with site-specific soil data where available (e.g., soil batch tests, etc.).

### Step 5: Input Application Data

Input a value of "25" for the number of years of model simulation data. This should be sufficient for most model simulations. The number of soil layers input is governed by the geologic profile determined for the site. **Include a 1cm- thick layer at the base**

**of the column and input the same soil/bedrock properties as the layer overlying it.** In the model simulation, this 1cm-thick layer directly overlies groundwater. Inclusion of a thin, basal layer is used to improve the precision of the SESOIL output data regarding the mass of contaminant moving from the vadose-zone into the groundwater (used in step 7).

The input application area reflects the areal extent of impacted soil and is used in conjunction with layer thickness to calculate contaminant mass. SESOIL automatically generates the site latitude based on the input climate station. The spill mode should be set to "Instantaneous" to reflect the one-time presence of residual contamination in the model impacted layer (i.e., no continuous source). "Pollutant Load" should be set to "Concentration" to reflect soil contaminant concentration as input in the next module. Washload simulations are not applicable for Tier 2 models.

#### Step 6: Input Soil Column Properties

Input thickness and permeability data for each geologic layer. Refer to the default permeability data provided in Table 2-5 where site-specific data are not available. The number of soil sublayers will normally be set to one.

For the layers underlying the uppermost unit, input a value of "1" for all soil-property, factoring parameters except organic carbon (OC). For organic carbon, input factors that reflect site-specific data where available. For sites where site-specific OC data are not available, assume an organic carbon content of 0.0001% for all lithified (rock) units and for all sediment and soil layers situated at greater than 3 meters depth (following assumptions used in Tier 1) and adjust the input OC factor values accordingly. For sites where mixtures of contaminants are present (e.g., petroleum), assume a maximum of 0.1% OC for soils within three meters of the surface and 0.0001% OC for all lithified units and for all layers situated at greater than 3 meters depth.

#### Step 7: Input Pollutant Loading Data

Input a value of "0" for the first data-input year of the "mass transformed", "sink", and "ligand" columns unless otherwise approved or directed by DOH. The input factor will be repeated for all subsequent years of data. **Input a value of "0.2" for "volatilization factor" to limit contaminant loss due to volatilization to 20% of the maximum possible (required).** Note that unlike the factors noted above the volatilization factor must be repeated for every simulation year. (Click on the column heading and use the column math function to expedite data input.) The application erroneously assumes a volatilization factor of 1 for all months where no data is input.

Input a value of "0" for the monthly pollutant load of each year of input data (i.e., the number of data-input years noted in Step 5) except the first month of the first year. Following the procedures outlined in Appendix D, adjust the input soil concentration for the 1<sup>st</sup> year, 1<sup>st</sup> month until the model is calibrated to target groundwater-

protection objective. **(Do not include assumed dilution of leachate at this point!)**

Step 8: Extract Groundwater-Impact SAL from Output Data.

Extract the SESOIL-generated SAL from the calibrated output file by following the procedures outlined in Appendix D. Change the SAL units to mg/kg. The final, site SAL for groundwater-protection concerns will be calculated by multiplying the SESOIL-generated SAL by the dilution attenuation factor determined for the site, as discussed below.

Unedited (except for format) output files for SESOIL model simulations must be included with the report documenting the derivation of each Tier 2 soil action level. The version of SESOIL used to generate the Tier 2 soil action levels must be clearly indicated in the report. Warning messages in the output file regarding input rainfall and permeability data are based on the input of extremely variable data and are intended to prompt the user to recheck the input data modules. If the input data is correct then the warnings can generally be ignored.

#### **GENERATION OF TIER 2 SALs FOR GROUNDWATER-PROTECTION CONCERNS - QUIKSOIL SPREADSHEET**

The QUIKSOIL spreadsheet model is based on a simple contaminant partitioning equation that approximates the dissolved-phase ("leachate") concentration of the contaminant in impacted soil based on the physio-chemical nature of the contaminant and the soil. The model is based on an equation presented in ASTM's "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (Table X2.1, ASTM, 1994)" for calculation of soil leaching factors:

$$SAL = C_w \times (Kd + (\theta_w + (\theta_a \times H'))/\rho_b),$$

where  $C_w$  is the target groundwater action level for the site (mg/L),  $Kd$  is the soil-water partition coefficient (L/Kg),  $\theta_w$  and  $\theta_a$  are the water- and air-filled porosities,  $H'$  is the Henry's law constant (unitless) and  $\rho_b$  is the soil bulk density.

Procedures regarding use of the QUIKSOIL spreadsheet to generate Tier 2 SALs are as follows:

- Step 1. Check with the DOH Solid and Hazardous Waste Branch to ensure that the spreadsheet you have is the most up-to-date version.
- Step 2. Input physio-chemical constants for the contaminant being evaluated. Constants for common contaminants are provided at the end of the spreadsheet (use "cut & paste" function of spreadsheet; refer also to Table 2-6). Contact the DOH Solid and Hazardous Waste Branch to obtain constants for contaminants not listed.

- Step 3. Input site data where available. (Model will use default, conservative parameter values where site data is not available.)
- Step 4. Input the target groundwater standard for the site (refer to Table 2-2). Do not include assumptions regarding dilution of leachate. Contact the DOH Solid and Hazardous Waste Branch to obtain groundwater criteria for contaminants not listed in Table 2-2.
- Step 5. Spreadsheet generates the contaminants Tier 2 SAL for groundwater-protection concerns at the site. Complete the information at the end of the first page of the spreadsheet. Include a copy of the spreadsheet for each contaminant modeled with the Tier 2 report submitted to DOH for review and approval.

An example printout of the QUIKSOIL spreadsheet is provided in Appendix H.

Users of the QUIKSOIL spreadsheet should be aware that the model does not incorporate DOH-acceptable assumptions regarding the fate and transport of the "leachate" in the vadose zone. With respect to the more comprehensive SESOIL application, the QUIKSOIL spreadsheet generates overly conservative SALs for contaminants that are highly biodegradable (e.g., half-life < 50 days) or highly volatile (e.g., Henry's Law constant > 0.01atm-m<sup>3</sup>/mol) or sites where the base of the impacted soil is situated greater than ten meters from groundwater. For contaminants or sites with these attributes, DOH strongly encourages use of the SESOIL application to generate groundwater-protection SALs.

### **CALCULATION OF FINAL SALs FOR GROUNDWATER-PROTECTION CONCERNS**

SALs generated with SESOIL (either Tier 1 SESOIL SALs provided in Appendix F or Tier 2, site-specific SESOIL SALs) or QUIKSOIL should be further refined on a site-specific basis to account for dilution of leachate as it mixes with groundwater. Because the relationship between leachate concentration and soil concentration is assumed to be linear (i.e., Freundlich number in SESOIL application set to "1"), refinement of a SESOIL- or QUIKSOIL-generated SAL is a simple matter of multiplying the SAL by a leachate dilution attenuation factor (DAF) calculated for the site.

Site-specific dilution attenuation factors are generated using the DOH spreadsheet entitled "DAF" (refer to example in Appendix I). The DAF equation relates the volume of recharge water infiltrating into groundwater beneath a site during a year to the volume of impacted groundwater passing beneath the site during that year as follows:

$$DAF = 1 + ((V_s \times d_m) \times n_{eff}) / (I \times L),$$

where "V<sub>s</sub>" (meters/year) is groundwater seepage velocity, "D<sub>m</sub>" (meters) is the mixing depth of the leachate in groundwater, "n<sub>eff</sub>" (m<sup>3</sup>/m<sup>3</sup>) is the fraction effective porosity, "I" (meters/year) is infiltration rate, and "L" (meters) is source length parallel to

groundwater flow.

Annual groundwater recharge is reported in the yearly summaries of SESOIL output files. If Tier 1, SESOIL-generated SALs or SALs based on the QUIKSOIL spreadsheet are used for the site then groundwater recharge can be estimated as an island-specific fraction of total annual rainfall. Assume the following recharge with respect to the location of the site (data from Atlas of Hawai'i, 1983): Ni'ihau: 5% total rainfall, Kaua'i: 16% total rainfall, O'ahu: 36% total rainfall, Moloka'i: 16% total rainfall, Maui: 30% total rainfall, Lāna'i: 12% total rainfall, Kaho'olawe: 10% total rainfall, and Hawai'i: 31% total rainfall.

The spreadsheet calculates groundwater velocity (seepage) as:

$$V_s = (K \times h)/n_{\text{eff}}$$

where "K" is the hydraulic conductivity of the groundwater bearing media in meters per year, "h" is the hydraulic gradient.

Mixing zone depth is calculated by relating source length parallel to groundwater flow, aquifer thickness ( $d_a$ , meters), and the hydraulic conductivity of the groundwater-bearing media as follows:

$$d_m = (0.0112 \times L^2)^{0.5} + d_a(1 - \exp[(-L \times I)/(K \times h \times d_a)]).$$

The dilution factor equation presented above is used in ASTM's "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites" (Table X2.1, ASTM, 1994). The mixing-zone depth equation is based on an equation published in EPA's *Technical Background Document for Soil Screening Guidance* (USEPA, 1994d).

Mixing-zone depths calculated using the equation will typically range between one and ten meters. The ASTM document referenced recommends a default mixing-zone depth of two meters. DAFs generated by the equations presented typically range from 1 to 10, dependent largely on annual rainfall, the hydraulic conductivity of the groundwater-bearing media, and the hydraulic gradient of the groundwater.

## GENERATION OF TIER 2 SALs FOR DIRECT-EXPOSURE CONCERNS

### Direct-Exposure Model Equations

The risk-based, deterministic models incorporated into the DETIER2 spreadsheet are based on slight modifications of direct-exposure models presented in the Second Half, 1994, and First Half, 1995, editions of EPA Region IX's "Preliminary Remediation Goals (PRGs)" (Appendix E, USEPA, 1994a, 1995). The equations used in the PRG models reflect guidance provided in the California EPA document entitled "Preliminary Endangerment Guidance Manual, January, 1994" (CAEPA, 1994). A copy of this



document is available from the DOH Solid and Hazardous Waste Branch.

Direct-exposure SALs for carcinogenic contaminants are calculated by solving equation 4-1 in the First Half, 1995, PRGs for C (refer to Appendix E). SALs for non-carcinogenic contaminants are similarly calculated by solving equation 4-2 for C. Note that the volatilization factor term in the direct-exposure models is replaced with the particulate emission factor term for non-volatile contaminants (defined as having a Henry's Law Constant ( $\text{atm}\cdot\text{m}^3/\text{mol}$ ) less than or equal to  $10^{-5}$  and a molecular weight less than 200 grams/mol).

In both equations, the air dispersion term incorporated into the volatilization and particulate emission factors should be modified to allow input of site-specific data. This reflects guidance presented in earlier editions of the PRGs. Refer to the discussion at the beginning of Appendix E for details on this modification.

### **Direct-Exposure Model Procedures**

Procedures regarding use of the Tier 2 direct-exposure spreadsheet to generate Tier 2 SALs are described below. Refer to the example printout in Appendix I.

- Step 1. Check with the DOH Solid and Hazardous Waste Branch to ensure that the spreadsheet you have is the most up-to-date version.
- Step 2. Check with DOH to ensure that the default toxicity data provided in the spreadsheet is up-to-date.
- Step 3. Input physio-chemical and toxicity constants for the contaminant being evaluated. Constants for common contaminants are provided at the end of the spreadsheet (use "cut & paste" function of spreadsheet; refer also to tables 2-5 and 2-7). Contact the DOH Solid and Hazardous Waste Branch to obtain constants for contaminants not listed.
- Step 4. Input site data where required and otherwise available (see page 1 of spreadsheet in Appendix I). Model will use default, conservative parameter values where site data is not available. Site parameters and default values (where applicable) incorporated into the Tier 2 direct-exposure models are noted in Table 2-9.

With the exception of windspeed, the default parameter values presented are the same as those used in the EPA PRG tables. The default windspeed of 2.5m/s given reflects one-half the 11mph average windspeed reported for Honolulu International Airport between 1985 and 1993 (USDOC, 1985-1993). (The average windspeed is divided by half to take into account interference by buildings, etc., in developed areas.)

- Step 5. Spreadsheet generates the contaminants Tier 2 SAL for direct-exposure

concerns at the site. Complete the information at the end of the first page of the spreadsheet. Include a copy of the spreadsheet for each contaminant modeled with the Tier 2 report submitted to DOH for review and approval (omit the equation check and physio-chemical constant table). If more than one contaminant is present above DOH Tier 1 criteria then contaminant-specific risks and hazard quotients should be added for final evaluation of the site.

An example printout of the DETIER2 spreadsheet is presented in Appendix I. A similar direct-exposure spreadsheet is available for use in Tier 3 site assessments (Appendix J, discussed below). Tier 1 direct-exposure SALs are given in Appendix F.

All site-specific parameter values used in the models must be supported by data collected from the subject site or from appropriate referenced sources. The data must be properly presented in a document submitted to the DOH for review (e.g., in a "Final Cleanup Progress Report" submitted to the DOH for underground storage tank release responses).

### **Default Exposure Assumptions**

Default, Tier 2 (and Tier 1) exposure assumptions are consistent with assumptions regarding residential exposure used in the EPA Region IX PRGs (Table 2-10). As in the PRG models, the Tier 2 models conservatively assume full exposure to a contaminant through inhalation, ingestion, and dermal absorption in a residential setting. Refer to the PRG reports in Appendix E for further discussion of the models and input assumptions.

### **MAXIMUM-ALLOWABLE SOIL ACTION LEVELS**

The site soil action level for any given contaminant should not exceed that contaminants Tier 1, theoretical saturation limit in soil. SESOIL generated saturation limits for common contaminants are given in Appendix F. Saturation levels for contaminants not included in the appendix should be derived by inputting the Tier 1 model scenario into the SESOIL application and following procedures described at the end of Appendix D (or contact DOH).

### **COMPARISON OF GROUNDWATER-PROTECTION AND DIRECT-EXPOSURE SALs**

Final, contaminant-specific soil action levels for a site are determined by comparing the results of the groundwater-impact models and direct-exposure models and selecting the SAL that corresponds to the impact of most concern (i.e., the most stringent action level) for the site. Four examples of Tier 2 site evaluations results are provided in Appendix I. Facilities should submit results of their evaluations in a similar format. Final closure reports for sites should include the results of the Tier 2 evaluation and include printouts of all model results. Report formats should follow guidance presented in the DOH TGM and subsequent updates (HIDOH, 1992, 1995a, 1995b,

1995c, 1995d). SESOIL and direct-exposure model results will be verified by DOH before final approval. Documentation of site-investigation data used in the models should be included or referenced in the report. Note that a map (drawn to scale) denoting the areal extent and thickness (use cross sections if necessary) of impacted soil left in place at the site must be submitted for all contaminants that exceed Tier 1 SALs.

## **APPLICATION TO SITES WITH IMPACTED GROUNDWATER**

As discussed in Chapter 1 for Tier 1 soil action levels, remediation of the impacted soils at sites where the main mass of contaminant has already reached and impacted groundwater should be guided in part by actual groundwater monitoring. In some cases, a groundwater investigation may indicate that impacted soil is not adversely impacting groundwater even though DAF-modified, Tier 2 SALs generated with SESOIL are exceeded (i.e., the theoretical SALs are too conservative). If this is the case, remediation of the impacted soil should be guided by direct-exposure concerns rather than groundwater-protection concerns. Conversely, a groundwater investigation may indicate that more stringent soil cleanup levels are warranted at the site (i.e., the theoretical SALs are not conservative enough). DOH anticipates the latter case will be the exception rather than the rule.

Groundwater contamination in excess of Tier 1 action levels may not necessarily require active remediation. When groundwater contamination in excess of Tier 1 action levels is discovered at a site, the extent and magnitude of contamination should be determined. If continued monitoring and, where appropriate, groundwater contaminant fate-and-transport modeling suggest that the plume of contaminated groundwater is not likely to migrate offsite and adversely impact groundwater extraction wells or surface water bodies then the contaminated groundwater can be left in place and allowed to degrade naturally over time. If this cannot be demonstrated then the contaminated groundwater should be actively remediated to Tier 1 action levels. Note that conclusions drawn from the results of contaminant fate-and-transport models must be supported by follow-up groundwater monitoring.

Unless otherwise approved or directed by DOH, downgradient monitoring of the plume can be discontinued when three successive seasonal cycles (generally three successive years) of groundwater monitoring indicate that the contaminated groundwater is not likely to migrate offsite and impact groundwater extraction wells or bodies of surface water at greater than Tier 1 action levels (i.e., the plume is stabilized). Monitoring of the body of groundwater that exceeds Tier 1 action levels should, however, be continued until contaminant levels drop below the action levels for two successive seasonal cycles. At this time DOH will issue a letter that no further investigative or remedial action is required at the site. Groundwater that is discharged from the site due to construction activities, etc., prior to this time must be tested for appropriate contaminants and adhere to discharge requirements put forth by the DOH Clean Water Branch.

### **TIER 3 RISK ASSESSMENTS**

Tier 3 risk assessments should follow guidelines presented in the DOH TGM and subsequent updates (HIDOH, 1992, 1995a). Risk assessments developed at this level might include some combination of alternative vadose-zone fate-and-transport models, direct-exposure models, and exposure pathway evaluations as well as more complex groundwater fate-and-transport models. All Tier 3 models and model assumptions must be fully documented and submitted to DOH for review and approval.

In the Tier 3 RBCA framework, the facility is allowed to propose alternative, acceptable levels of risk at the site. DOH recommends, however, that the target risk following completion of remedial actions be set at  $10^{-6}$ . If a facility cannot feasibly meet this primary objective, however, but can get to within the EPA-designated acceptable risk range of  $10^{-4}$  to  $10^{-6}$ , then the facility should meet with the appropriate DOH office and demonstrate that additional remedial work cannot feasibly be carried out, given technological and economic constraints, etc. In reality, this may be a common scenario at large sites with extensive but relatively low levels of contamination.

DOH has prepared a direct-exposure spreadsheet for Tier 3 site evaluations (DETIER3). An example printout of the spreadsheet is provided in Appendix J. Incorporation of the spreadsheet in the Tier 3 evaluation is not required, though its use may help expedite review of the risk assessment.

The spreadsheet can also be used to calculate risk due to volatilization from groundwater (required only on a site-by-site basis by DOH). Simply assume that 90% of the total porosity is water-filled/saturated and run the model as usual (e.g. if total porosity = 43%, soil is 90% saturated when soil moisture content = 0.25ml/g .).

Table 2-1. Example generation of Tier 2 SALs. Site - Inland area over basal, unconfined, drinking water groundwater system in basalt; base of impacted soil  $\geq 10\text{m}$  above top of groundwater; moderate rainfall (150cm/year); areal extent of soil impacted above Tier 1 SALs =  $900\text{m}^2$ , thickness of soil impacted above Tier 1 SALs = 2m (assumed same for each contaminant)

<sup>1</sup> Contaminant	<sup>2</sup> SESOIL SAL (mg/kg)	<sup>3</sup> Site DAF	<sup>4</sup> Groundwater Protection SAL (mg/kg)	<sup>5</sup> Direct-Exposure SAL (mg/kg)	<sup>6</sup> SAL chosen for site (mg/kg)
Benzene	0.027	2.5	0.07	6.8	<b>0.07</b>
Toluene	124	2.5	<sup>4</sup> 170sat	5340	<b>170</b>
PCE	2.3	2.5	5.8	5.8	<b>5.8</b>

1. Contaminants noted exceeded Tier 1 soil action levels (SALs) at the example site.
2. Default Tier 1 SESOIL SALs for groundwater protection taken from lookup table rather than re-running SESOIL to generate site-specific SALs for groundwater protection (refer to Appendix F, Table 1a).
3. Site dilution attenuation factor (DAF) as calculated using DAF spreadsheet.
4. Site SALs for groundwater-protection concerns calculated by multiplying the SESOIL SAL times the leachate dilution attenuation factor determined for the site. Maximum groundwater-protection SAL is the contaminants theoretical saturation limit ("sat", refer to Appendix F, Table 2).
5. Contaminant direct-exposure SALs as calculated using DETIER2 spreadsheet.
6. SAL chosen for site reflects the contaminant pathway of most concern.

TABLE 2-2. Tier 1 and Tier 2 groundwater protection standards

Contaminant	<sup>1,2</sup> Current/Potential Drinking Water Resource (mg/l)	<sup>1,3</sup> Non-Drinking Water Resource (mg/l)
Benzene	0.005	1.7
Toluene	1.0	2.1
Ethylbenzene	(0.14)	0.14
Xylene	10	[10]
Benzo(a)pyrene	0.0002	[0.0002]
Acenaphthene	(0.32)	0.32
Fluoranthene	(0.013)	0.013
Naphthalene	<sup>5</sup> 0.24	0.77
PCE	0.005	<sup>4</sup> 0.145
1,1 DCE	0.046	3.9
Vinyl Chloride	0.002	[0.002]
TCE	0.005	0.70
1,1,1 TCA	0.20	6.0
Lead (total)	(0.0056)	<sup>4</sup> 0.0056
Cadmium	0.005	<sup>4</sup> 0.0093
PCBs	0.0005	<sup>6</sup> 0.002

() Same as surface water; surface-water standard more stringent than drinking water standard.

[] Same as drinking water; surface-water standards not set.

1. Groundwater utility as defined by DOH (refer to HIDOH, 1995b).

2. Drinking water MCL for contaminant unless otherwise noted (HAR Chapter 11-20, 1994).

3. Surface water acute standard (or chronic standard where available and applicable) for contaminant unless otherwise noted (HAR Chapter 11-54, 1992).

4. Marine chronic surface water quality standard as established in HAR, HAR 11-54.

5. Drinking water criteria provided in USEPA Region IX Preliminary Remediation Goals document (USEPA, 1995).

6. Ecology-based, freshwater acute standard used for PCBs. Both freshwater and chronic standards are based on FDA action levels for PCBs in fish for commercial consumption rather than ecological impact.

Table 2-3. Site parameters and default values used in Tier 1 SESOIL models

<b><u>Climate Data:</u></b>	<b><u><sup>1</sup>Default Values</u></b>		
Air Temperature:	month-specific		
Evapotranspiration (cm/day):	36% of rainfall, month specific		
Precipitation (cm/month):	200cm/year, month-specific		
Storm Duration (days)	month-specific		
Number of Storms:	month-specific		
Days per Month:	30.4 (default, all months)		
<b><u>Soil Properties:</u></b>			
Bulk Density (g/cm <sup>3</sup> ):	1.3		
Intrinsic Permeability (cm <sup>2</sup> ):	specified in soil column input		
Disconnectedness Index:	3.5		
Effective Porosity:	0.3		
Organic Carbon Content (%):	0.1		
Cation Exchange Capacity (meq/100g):	0		
Freundlich Equation Exponent:	1.0		
<b><u>Soil Column Properties:</u></b>			
<u>Layers</u>	<u><sup>2</sup>Thickness</u>	<u><sup>3</sup>Permeability</u>	<u><sup>4</sup>Organic Carbon</u>
soil	site specific	1E-07cm <sup>2</sup>	0.1%
basalt/bedrock	site specific	1E-06cm <sup>2</sup>	0.0001%

1. Refer to default values presented in Table 2-4 for month-specific data.

2. Total thickness reflects assumed depth to groundwater.

3. Values used in Tier 1 models. Refer to Table 2-5 for default permeability values.

4. Foc as a fraction of input soil property value.

TABLE 2-4. Monthly climate data used in Tier 1 SESOIL standard-rainfall models.  
(Modified Ahuimanu Loop climate station data)

Month	<sup>1</sup> Air Temperature (°C)	<sup>2</sup> Evapotranspiration (cm/day)	<sup>3</sup> Precipitation (cm/month)	Duration (days)	Number of Storms	Month Length (days)
Oct.	25	0.21	12.02	0.31	12.2	30.4
Nov.	24	0.24	14.06	0.36	12.2	30.4
Dec.	23	0.28	15.90	0.43	11.1	30.4
Jan.	22	0.39	22.54	0.50	10.0	30.4
Feb.	22	0.22	12.88	0.35	10.1	30.4
Mar.	22	0.28	16.37	0.33	12.6	30.4
Apr.	23	0.27	15.32	0.36	13.6	30.4
May	24	0.18	10.68	0.27	13.0	30.4
June	25	0.14	7.87	0.26	11.5	30.4
July	25	0.14	8.10	0.29	12.5	30.4
Aug.	25	0.16	9.19	0.26	12.8	30.4
Sept.	25	0.14	7.92	0.23	11.8	30.4

Annual Totals: Precipitation: 200cm, Evapotranspiration: 80cm, Surface Runoff: 48cm (Groundwater Recharge = 72cm)

1. Air temperature data from Kāne'ohe Mauka climate station (Owenby and Ezell, 1992). All other data modified from 'Āhuimanu Loop climate station.
2. Evapotranspiration calculated as 40% of daily rainfall.
3. 'Āhuimanu Loop monthly precipitation adjusted to produce 200cm annual rainfall versus actual 223cm/yr. Input precipitation reduced by 24% to account for surface runoff.



TABLE 2-5. Physical properties of basalt and common soil types in Hawai'i

Properties	Basalt	Saprolite (a)/ silty sediment	Saprolite (b)	Clay (c)	Sand
Range Hydraulic Conductivity (in/hr)	-	2 to 6	0.6 to 2.0	0.06 to 0.2	6 to 20
Range Hydraulic Conductivity (m/d)	up to 300+	1 to 4	0.1 to 0.4	0.04 to 0.12	4 to 12
Range Permeability (cm <sup>2</sup> )	1E-8 to 4E-6	1E-8 to 5E-8	5E-9 to 1E-8	5E-10 to 5E-9	5E-8 to 1E-7
Model Hydraulic Conductivity (m/d)	100	4	0.4	0.2	12
Model Permeability (cm <sup>2</sup> )	1E-06	5E-08	5E-09	2E-9	1E-07
Organic Carbon at >50cm depth (%)	no data (0%)	0 to 1.0%	0 to 1.0%	highly variable	0 to 0.1%
Bulk Density (g/cm <sup>3</sup> )	1.6	1.3	1.3	1.3	1.7

Saprolite (a): Silty clay - Wahiawā, Helemano, Waikāne, Loleka'a soil series.

Saprolite (b): Silty clay - 'Ewa, Waialua soil series.

Clay (c): Lualualei, Ka'ena series.

Sources of published data:

1. Soil Survey of the Islands of Kaua'i, O'ahu, Maui, Moloka'i, and Lāna'i, State of Hawai'i (Foote et al., 1972);
2. Soil Survey Laboratory Data and Descriptions for Some Soils of Hawai'i (USDOA, 1976);
3. Hydrogeologic Characteristics of Subsoil and Saprolite and Their Relation to Contaminant Transport, Central O'ahu, Hawai'i (Miller et al., 1988);
4. Aquifer Identification and Classification for O'ahu (Mink and Lau, 1990);
5. Hawai'i Field Office Technical Guide (Section II, Engineering Index Properties, USDOA, 1992).

TABLE 2-6. Default, physio-chemical constants for common contaminants

<sup>1</sup> Constituent	Water Solubility (mg/l)	Diffusion Coefficient-air (cm <sup>2</sup> /s)	Henry's Constant (m <sup>3</sup> -atm/mole)	KOC (ml/g)	Molecular Weight
Benzene	1800	0.088	0.0055	65	78
Toluene	520	0.078	0.0066	260	260
Ethylbenzene	680	0.075	0.0079	220	110
Xylene (mixed)	200	0.087	0.0053	240	110
<sup>2</sup> Benzo(a)pyrene	0.0039	0.045	0.0000024	881000	252
Acenaphthene	4	0.064	0.0012	4600	150
<sup>2</sup> Fluoranthene	0.26	0.051	0.0000087	41700	202
Naphthalene	31	0.069	0.0013	1300	130
PCE	150	0.072	0.023	660	170
1,1 DCE	400	0.079	0.15	65	97
Vinyl Chloride	1100	0.110	0.70	57	63
TCE	1000	0.081	0.0089	130	130
1,1,1 TCA	950	0.080	0.0028	150	130

1. Source of data USEPA (1995) unless otherwise noted.
2. Data after Montgomery and Welkom (1991) and Neff et al. (1994).

TABLE 2-7. Default biodegradation constants for use in Tier 2 SESOIL models

Constituent	Range Aerobic Half- life (days)	Range Anaerobic Half- life (days)	Model Liquid- Phase Half- life (days)	Model Liquid- Phase Biodegradation Rate (1/days)	Model Solid- Phase Biodegradation Rate (1/days)
Benzene	5 to 16	112 to 730	112	0.0062	0.0031
Toluene	4 to 22	56 to 210	56	0.0124	0.0062
Ethylbenzene	3 to 10	176 to 228	176	0.0039	0.0020
Xylene (mixed)	7 to 28	180 to 365	180	0.0039	0.0019
Benzo(a)pyrene	56 to 529	228 to 2117	529	0.0013	0.0007
Acenaphthene	12.3 to 102	49.2 to 408	102	0.0068	0.0034
Fluoranthene	140 to 440	558 to 1774	558	0.0012	0.0006
Naphthalene	0.5 to 20	25 to 258	25	0.0277	0.0139
PCE	180 to 365	98 to 1643	365	0.0019	0.0009
1,1 DCE	28 to 180	81 to 173	180	0.0039	0.0019
Vinyl Chloride	28 to 180	112 to 730	180	0.0039	0.0019
TCE	180 to 365	98 to 1642	365	0.0019	0.0009
1,1,1 TCA	140 to 273	560 to 1092	560	0.0012	0.0006

Half-life data after Howard et al. (1991).

TABLE 2-8. Toxicity data for common contaminants

Contaminant	Cancer Slope Factor (oral) [1/(mg/kg-d)]	Cancer Slope Factor (inhalation) [1/(mg/kg-d)]	Reference Dose (oral) [mg/kg-d]	Reference Dose (inhalation) [mg/kg-d]
Benzene	2.90E-02	2.90E-02		
Toluene			2.00E-01	1.10E-01
Ethylbenzene			1.00E-01	2.90E-01
Xylene			2.00E+00	2.00E-01
Benzo(a)pyrene	7.30E+00	7.30E+00		
Acenaphthene			6.00E-02	6.00E-02
Fluoranthene			4.00E-02	4.00E-02
Naphthalene			4.00E-02	4.00E-02
PCE	5.20E-02	2.00E-02	1.00E-02	1.00E-02
1,1 DCE	6.00E-01	1.80E-01	9.00E-03	9.00E-03
Vinyl Chloride	1.90E+00	3.00E-01		
TCE	1.1E-02	6.0E-03	6.0E-03	6.0E-03
1,1,1 TCA			9.0E-02	2.9E-01

Source of data: USEPA IRIS and HEAST data bases (USEPA, 1994b, 1994c)

TABLE 2-9. Direct-exposure site parameters and default values

	<u><sup>1</sup>Default Values</u>
Areal extent of contamination (meters <sup>2</sup> )	2025m <sup>2</sup>
Soil density (grams/meter <sup>3</sup> )	1.50g/m <sup>3</sup>
Particle density (grams/meter <sup>3</sup> )	2.65g/m <sup>3</sup>
Soil porosity (total)	43%
Soil air-filled porosity	28%
Soil moisture content (milliliters water/grams soil)	10ml/g
Fraction organic carbon	0.02
Average wind speed (meters/second)	2.5m/s (5.5mph)

1. Same as used for EPA Region IX Preliminary Remediation Goals (USEPA, 1995).

TABLE 2-10. Direct-exposure human-receptor parameters and default values

Human Receptor Data	Default
25% surface area - adults (cm <sup>2</sup> )	5000
25% surface area - children (cm <sup>2</sup> )	2000
Adherence factor (unitless)	0.2
Inhalation Rate - adults (m <sup>3</sup> /d)	20
Inhalation Rate - children (m <sup>3</sup> /d)	10
Soil ingestion rate - adults (mg/d)	100
Soil ingestion rate - children (mg/d)	200
Exposure time - residents (h/d)	24
Exposure frequency - residents (d/y)	350
Exposure duration - residents total (yrs)	30
Exposure duration - children (yrs)	6
Body weight - adult (kg)	70
Body weight - child (kg)	15
Averaging time (yrs)	70
<b>Other variables</b>	
Diffusion height (m)	2

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STATE OF HAWAII  
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P.O. BOX 3378  
HONOLULU, HAWAII 96801

In reply, please refer to  
EMD/SHW

TO: ALL USERS OF THE DOH RBCA MANUAL

SUBJECT: Addendum to: *Risk-Based Corrective Action (RBCA) and Decision Making at Sites With Contaminated Soil and Groundwater (December 15, 1995)*

**Extent of Contamination**

(Volume I, page 18; DETIER2 & DETIER3 spreadsheets)

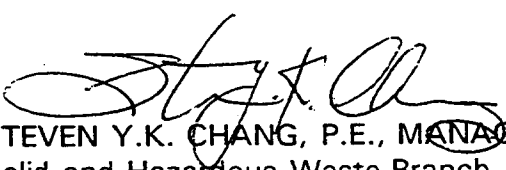
At all sites where contaminated soil is discovered, the vertical and lateral extent of contamination must be delineated out to Tier 1 soil action levels unless otherwise approved or directed by the Department of Health (DOH). For the purpose of conducting a Tier 2 or Tier 3 direct-exposure assessment at a site, the extent of soil contamination input into the models must at a minimum take into account the volume of soil that exceeds the Tier 1 direct-exposure action level for the contaminant of concern. Tier 1 direct-exposure action levels for common contaminants can be found in Appendix F, Table 3. DOH should be contacted for Tier 1 direct-exposure action levels for contaminants not listed in the table.


Evaluating risk based only on "hot spots" of contaminated soil that exceed Tier 1 direct-exposure action levels may, however, be overly conservative for sites where the extent of contamination is limited. Where additional site data are available, Tier 2 and Tier 3 direct-exposure assessments should be based on the full, known extent of soil contamination as determined during the site investigation. Note that for sites with hot spot sizes that exceed assumptions used in the Tier 1 models (e.g., areal extent of contamination greater than 2025 m<sup>2</sup>, thickness of impacted soil greater than 2m) it may be necessary to assess the risk posed by the hot spot separately.

**Model Soil Contaminant Concentrations**

(Volume I, page 27, 31; DETIER2 & DETIER3 spreadsheets)

For the purpose of comparing the results of a Tier 2 direct-exposure assessment to site data or for the purpose of conducting a Tier 3 direct-exposure assessment, the maximum contaminant concentration detected in soil at a site should be used if site data are limited. In cases where there is adequate site characterization, and subject to review and approval by DOH, the 95<sup>th</sup> percent, upper confidence limit of the arithmetic mean of the sample results may be substituted.

  
STEVEN Y.K. CHANG, P.E., MANAGER  
Solid and Hazardous Waste Branch

  
STEVEN ARMANN, ACTING MANAGER  
Office of Hazard Evaluation and Emergency  
Response

Date: 2/16/96

Date: 2/20/96

**RISK-BASED CORRECTIVE ACTION AND DECISION MAKING AT SITES  
WITH CONTAMINATED SOIL AND GROUNDWATER**

**VOLUME I**

**ADDENDUM #2**

**ADDITIONS/UPDATES TO TIER 1 LOOKUP TABLES**

**(June 6, 1996)**

**State of Hawai'i Department of Health  
919 Ala Moana Blvd, Room 212  
Honolulu, Hawai'i 96814**

**(808-586-4226)**

**RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)**

**ADDITIONS/UPDATES TO TIER 1 LOOKUP TABLES**  
(June 6, 1996)

**TABLE 1-1a (cont.). Tier 1 Action Levels for soil and groundwater: Rainfall  $\leq 200$ cm/year**

RAINFALL $\leq 200$ CM/YEAR					
Contaminant	DRINKING WATER SOURCE THREATENED		DRINKING WATER SOURCE NOT THREATENED		Date Added/ Updated
	Groundwater (mg/l)	Soil (mg/kg):	Groundwater (mg/l)	Soil (mg/kg):	
Acetone	0.61	5.8	[0.61]	5.8	2/24/96
Chlorobenzene	0.10	0.08	[0.10]	0.08	2/24/96
Chloroform	0.00016	0.001	9.6	2.8de	2/24/96
4,4 DDD	0.0003	1.8de	0.0006	1.8de	2/29/96
4,4 DDE	0.0002	1.3de	0.014	1.3de	2/24/96
4,4 DDT	0.0002	0.82sat	0.000001	0.82sat	2/24/96
Di-n-octyl phthalate	0.73	31sat	[0.73]	31sat	6/6/96
Ethylene glycol	73,000	18,000sat	[73,000]	18,000sat	2/24/96
Methylene chloride	0.0043	0.003	[0.0043]	0.003	2/24/96
2,3,7,8 TCDD (Dioxin)	4.5E-10	0.000004de	0.000003	0.000004de	6/6/96
Chlordane	0.002	0.38de	0.0043	0.38de	6/12/96
Carbon tetrachloride	0.005	0.15	12	1.9de	6/12/96

**ADDITIONS/UPDATES TO TIER 1 LOOKUP TABLES**  
(June 6, 1996)

**TABLE 1-1b (cont.). Tier 1 Action Levels for soil and groundwater: Rainfall > 200cm/year**

RAINFALL > 200CM/YEAR					
Contaminant	DRINKING WATER SOURCE THREATENED		DRINKING WATER SOURCE NOT THREATENED		Date Added/ Updated
	Groundwater (mg/l)	Soil (mg/kg):	Groundwater (mg/l)	Soil (mg/kg):	
Acetone	0.61	0.06	[0.61]	0.06	2/24/96
Chlorobenzene	0.10	0.05	[0.10]	0.05	2/24/96
Chloroform	0.00016	0.0001	9.6	2.8de	2/24/96
4,4 DDD	0.0003	1.8de	0.0006	1.8de	2/29/96
4,4 DDE	0.0002	1.3de	0.014	1.3de	2/24/96
4,4 DDT	0.0002	0.82sat	0.000001	0.82sat	2/24/96
Di-n-octyl phthalate	0.73	31sat	[0.73]	31sat	6/6/96
Ethylene glycol	73,000	18,000sat	[73,000]	18,000sat	2/24/96
Methylene chloride	0.0043	0.002	[0.0043]	0.002	2/24/96
2,3,7,8 TCDD (Dioxin)	4.5E-10	0.000004de	0.000003	0.000004de	6/6/96
Chlordane	0.002	0.38de	0.0043	0.38de	6/12/96
Carbon tetrachloride	0.005	0.024	12	1.9de	6/12/96

TABLE 1-1 (cont.). Tier 1 Action Levels for soil and groundwater: Notes

**ANNOTATIONS:**

unmarked criteria: groundwater-protection concerns dominate

de: direct-exposure concerns dominate

sat: saturation concentration, groundwater-protection concerns dominate

() Same as surface water; surface water standard more stringent than drinkingwater standard.

[] Same as drinking water; surface water standards not set.

PCE: tetrachloroethylene, DCE: dichloroethylene, TCE: trichloroethylene, TCA:

trichloroethane, PCBs: polychlorinated biphenyls, TPH: total petroleum hydrocarbons

**NOTES:**

1. Determination of groundwater utility should be determined based on the DOH policy *Determination of Groundwater Utility at Leaking Underground Storage Tank Sites (September 13, 1995)*. (HIDOH, 1995b)
2. TPH criteria as presented in *Reporting, Remediation, and Management of Petroleum-Contaminated Soil (December, 1995)*. (HIDOH, 1995d). Gasolines: characterized by a predominance of alkyl benzenes and straight-chain, branched, and cyclo- alkanes and alkenes with carbon ranges of C6 to C12. Middles distillates (e.g., kerosene, diesel fuel, home heating fuel, jet fuel, etc.): characterized by a predominance of straight-chain alkanes and polynuclear aromatic hydrocarbons with carbon ranges of C12 to C24. Residual fuels: characterized by long chain alkanes (carbon range > C24) and less predominant aromatics that include phenathrenes, benzopyrenes, and other polynuclear aromatic hydrocarbons.
3. The facility should contact DOH for further guidance when laboratory practical quantification limits exceed the recommended groundwater criteria.
4. Lowermost limit on soil action levels for benzene leachate concerns set at 0.05mg/kg based on field experience rather than adhering to SESOIL results. (See Chapter 1.)
5. Soil action levels set for leachate-impact concerns (SALs not annotated with "sat" or "de") assume depth to groundwater is two meters or less and assume no dilution of leachate in groundwater (i.e., Dilution Attenuation Factor (DAF) = 1. Not applicable to TPH criteria. See Chapter 2 and Table 1 in Appendix F.).
6. Refer to Tier 2 discussion (Chapter 2) for guidance on adjustment of Tier 1 leachate-impact SALs with respect to depth to groundwater from the base of the impacted soil and site-specific DAFs.

**GROUNDWATER-IMPACT MODEL (see text)**

Climate data: Standard rainfall models: 'Āhuimanu Loop station data adjusted to 200cm annual rainfall.

High rainfall models: Honomu Mauka station data adjusted to 400cm annual rainfall.

Geologic model: Sand or very permeable saprolite/soil overlying fractured, porous basalt.

**DIRECT-EXPOSURE MODEL (see text)**

Assumes long-term residential exposure to impacted soil through inhalation, ingestion, and dermal absorption.

**RISK-BASED CORRECTIVE ACTION AND DECISION MAKING AT SITES  
WITH CONTAMINATED SOIL AND GROUNDWATER**

**VOLUME I**

**ADDENDUM #2**

**SUPPORTING DATA**

**(June 6, 1996)**

# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 1. Physio-chemical constants used in Tier 1 SESOIL models.

<sup>1</sup> Constituent	Water Solubility (mg/l)	Diffusion Coefficient t-air (cm <sup>2</sup> /s)	Henry's Constant (m <sup>3</sup> -atm/mole)	KOC (ml/g)	Molecular Weight
<sup>1</sup> Acetone	miscible	0.10	2.1E-05	2.2	58
<sup>1</sup> Chlorobenzene	470	0.072	3.5E-03	160	110
<sup>1</sup> Chloroform	8,200	0.089	3.8E-03	31	120
<sup>2</sup> 4,4 DDD	0.16	no data	2.16E-05	780,000	320
<sup>2</sup> 4,4 DDE	0.12	no data	6.8E-05	<sup>4</sup> 4,400,000	318
<sup>2</sup> 4,4 DDT	0.0034	no data	5.13E-04	240,000	354
<sup>2</sup> Di-n-octyl phthalate	1.6	no data	3.6E-05	19,000	391
<sup>3</sup> Ethylene glycol	miscible	no data	2.34E-10	<sup>4</sup> 4	62
<sup>1</sup> Methylene chloride	13,200	0.10	2.6E-03	8.8	85
<sup>2</sup> PCBs (1260 Arochlor)	0.08	no data	4.6E-3	<sup>4</sup> 1,400,000	376
<sup>2</sup> 2,3,7,8 TCDD (Dioxin)	0.014	no data	8.1E-05	13,000,000	322
<sup>2</sup> Chlordane	0.95	no data	6.0E-05	23,000	410
<sup>1</sup> Carbon tetrachloride	760	0.060	0.024	110	150

1. Source of data USEPA (1995)
2. Source of data ADSTR
3. Source of data TOMES database
4. Koc estimated from Kow



# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 2. Toxicity data used in Tier 1 direct-exposure models.

Contaminant	Cancer Slope Factor (oral) [1/(mg/kg-d)]	Cancer Slope Factor (inhalation) [1/(mg/kg-d)]	Reference Dose (oral) [mg/kg-d]	Reference Dose (inhalation) [mg/kg-d]
Acetone			1.0E-01	1.0E-01
Chlorobenzene			2.0E-02	5.7E-03
Chloroform	6.1E-03	8.1E-02	1.0E-02	1.0E-02
4,4 DDD	2.4E-01	2.4E-01		
4,4 DDE	3.4E-01	3.4E-01		
4,4 DDT	3.4E-01	3.4E-01	5.0E-04	5.0E-04
Di-n-octyl phthalate			2.0E-02	2.0E-02
Ethylene glycol			2.0E+00	2.0E+00
Methylene chloride	7.5E-03	1.6E-03	6.0E-02	8.6E-01
PCBs (1260 Arochlor)	7.7E+00	7.7E+00		
2,3,7,8 TCDD (Dioxin)	1.5E+05	1.5E+05		
Chlordane	1.3E+00	1.3E+00	6.0E-05	6.0E-05
Carbon tetrachloride	1.3E-01	5.3E-02	7.0E-4	5.7E-04

\*Source of data USEPA (1995)

# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 3. Biodegradation constants used in Tier 1 SESOIL models.

Constituent	Range Aerobic Half-life (days)	Range Anaerobic Half- life (days)	Model Liquid-Phase Half-life (days)	Model Liquid- Phase Biodegradation Rate (1/days)	Model Solid- Phase Biodegradation Rate (1/days)
Acetone	1 to 7	4 to 28	7	0.0990	0.0495
Chlorobenzene	68 to 150	272 to 600	272	0.0025	0.0013
Chloroform	28 to 180	7 to 28	28	0.0248	0.0124
4,4 DDD	730 to 5694	70 to 294	730	0.0009	0.0005
4,4 DDE	730 to 5694	16 to 100	730	0.0009	0.0005
4,4 DDT	730 to 5694	16 to 100	730	0.0009	0.0005
Di-n-octyl phthalate	7 to 28	180 to 365	180	0.0039	0.0019
Ethylene glycol	2 to 12	8 to 48	12	0.0578	0.0289
Methylene chloride	7 to 28	28 to 112	28	0.0248	0.0124
PCBs (1260 Arochlor)	no data				
2,3,7,8 TCDD (Dioxin)	420 to 591	1671 to 2354	1671	0.0004	0.0002
Chlordane	283 to 1387	1 to 7	283	0.0024	0.0012
Carbon tetrachloride	180 to 365	7 to 28	180	0.0039	0.0019

Half-life data after Howard et al. (1991).

# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 4. Tier 1 and Tier 2 groundwater protection standards

Contaminant	<sup>1,2</sup> Current/Potential Drinking Water Resource (mg/l)	<sup>1,3</sup> Non-Drinking Water Resource (mg/l)
Acetone	<sup>5</sup> 0.61	[0.61]
Chlorobenzene	0.10	[0.10]
Chloroform	<sup>5</sup> 0.00016	9.6
4,4 DDD	<sup>5</sup> 0.0003	<sup>8</sup> 0.0006
4,4 DDE	<sup>5</sup> 0.0002	<sup>7</sup> 0.014
4,4 DDT	<sup>5</sup> 0.0002	<sup>7</sup> 0.000001
Di-n-octyl phthalate	<sup>5</sup> 0.73	[0.73]
Ethylene glycol	<sup>5</sup> 73,000	[73,000]
Methylene chloride	<sup>5</sup> 0.0043	[0.0043]
PCBs (1260 Arochlor)	0.0005	<sup>6</sup> 0.002
2,3,7,8 TCDD (Dioxin)	<sup>5</sup> 4.5E-10	0.000003
Chlordane	0.002	0.0043
Carbon tetrachloride	0.005	12

- ( ) Same as surface water; surface-water standard more stringent than drinking water standard.  
 [ ] Same as drinking water; surface-water standards not set.
1. Groundwater utility as defined by DOH (refer to HIDOH, 1995b).
  2. Drinking water MCL for contaminant unless otherwise noted (HAR Chapter 11-20, 1994).
  3. Surface water acute standard (or chronic standard where available and applicable) for contaminant unless otherwise noted (HAR Chapter 11-54, 1992).
  4. Marine chronic surface water quality standard as established in HAR 11-54.
  5. Drinking water criteria provided in USEPA Region IX Preliminary Remediation Goals document (USEPA, 1995).
  6. Ecology-based, freshwater acute standard used for PCBs. (HAR Chapter 11-54, 1992, surface water chronic standards are based on FDA action levels for PCBs in fish for commercial consumption rather than ecological impact and were not used in this study.)
  7. Marine acute surface water standard (or chronic standard where available) from USEPA Quality Criteria for Water (1992).
  8. Fresh water acute surface water standard (or chronic standard where available) from USEPA Quality Criteria for Water (1992).

## RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 5. Tier 1 contaminant soil saturation levels.

Contaminant	<sup>1</sup> Contaminant Saturation Soil Action Level (mg/kg)
Acetone	16,000
Chlorobenzene	94
Chloroform	610
4,4 DDD	124
4,4 DDE	530
4,4 DDT	0.82
Di-n-octyl phthalate	31
Ethylene glycol	18,000
Methylene chloride	870
2,3,7,8 TCDD (Dioxin)	70
Chlordane	22
Carbon tetrachloride	232

1. Soil saturation levels generated using SESOIL unless otherwise noted. Saturation levels presented for common petroleum constituents address potential mobilization of the free product mixture as a whole rather than a specific contaminant. See text.

# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 6. Additional Tier 1, SESOIL-generated soil action levels for groundwater-protection concerns.

Contaminant	DRINKING WATER SOURCE THREATENED			DRINKING WATER SOURCE NOT THREATENED		
	Groundwater Action Level (mg/l)	Soil Action Level (mg/kg) [Standard Rainfall ( $\leq 200\text{cm/yr}$ )]	Soil Action Level (mg/kg) [High Rainfall ( $> 200\text{cm/yr}$ )]	Groundwater Action Level (mg/l)	Soil Action Level (mg/kg) [Standard Rainfall ( $\leq 200\text{cm/yr}$ )]	Soil Action Level (mg/kg) [High Rainfall ( $> 200\text{cm/yr}$ )]
Acetone	0.61	5.8	0.06	0.61	5.8	0.06
Chlorobenzene	0.10	0.08	0.05	0.10	0.08	0.05
Chloroform	0.00016	0.001	0.0001	9.6	42	6.0
4,4 DDD	0.0003	120sat	120sat	0.0006	120sat	120sat
4,4 DDE	0.0002	530sat	530sat	0.014	530sat	530sat
4,4 DDT	0.0002	0.82sat	0.82sat	0.000001	0.82sat	0.82sat
Di-n-octyl phthalate	0.73	31sat	31sat	0.73	31sat	31sat
Ethylene glycol	73,000	18,000sat	18,000sat	73,000	18,000sat	18,000sat
Methylene chloride	0.0043	0.003	0.002	0.0043	0.003	0.002
PCBs (1260 Arochlor)	0.0005	11sat	11sat	0.002	11sat	11sat
2,3,7,8 TCDD (Dioxin)	4.5E-10	70sat	70sat	0.0000003	70sat	70sat
Chlordane	0.002	22sat	22sat	0.0043	22sat	22sat
Carbon tetrachloride	0.005	0.15	0.024	12	232sat	58

\* sat = saturated (maximum allowable soil action level, see table 6)

# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 7. Tier 1 direct-exposure soil action levels.

Contaminant	<sup>1</sup> Direct-Exposure Soil Action Level (mg/kg)
Acetone	3,000
Chlorobenzene	250
Chloroform	2.8
4,4 DDD	1.8
4,4 DDE	1.3
4,4 DDT	1.3
Di-n-octyl phthalate	1,300
Ethylene glycol	130,000
Methylene chloride	42
PCBs (1260 Arochlor) (default value set by DOH, residential risk = 1.8E-05)	1
2,3,7,8 TCDD (Dioxin)	0.000004
Chlordane	0.38
Carbon tetrachloride	1.9

1. Direct-exposure soil action levels generated by use of risk-based, quantitative models (DOH DETIER1 spreadsheet) unless otherwise noted. SALs set to meet a  $10^{-6}$  risk or hazard quotient of 1 (rounded off to two significant digits). See text.

# RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 8. Generation of Tier 1 soil action levels: Drinking water source threatened, rainfall  $\leq 200\text{cm/yr}$ .

REFERENCE: HIDOH. 1995a. *Risk-Based Corrective Actions and Decision Making at Sites With Contaminated Soil and Groundwater*: State of Hawai'i Department of Health, Environmental Management Division.

Contaminant	Groundwater Action Level (mg/l)	<sup>1</sup> Groundwater -Protection SAL (mg/kg)	<sup>2</sup> Direct-Exposure SAL (mg/kg)	<sup>3</sup> TIER 1 Soil Action Level (mg/kg)
Acetone	0.61	5.8	3,000	5.8
Chlorobenzene	0.10	0.08	250	0.08
Chloroform	0.00016	0.001	2.8	0.001
4,4 DDD	0.0003	120	1.8	1.8
4,4 DDE	0.0002	530	1.3	1.3
4,4 DDT	0.0002	0.82	1.3	0.82
Di-n-octyl phthalate	0.73	31	1,300	31
Ethylene glycol	73,000	18,000	130,000	18,000
Methylene chloride	0.0043	0.003	42	0.003
PCBs (1260 Arochlor)	0.0005	11	1	1
2,3,7,8 TCDD (Dioxin)	4.5E-10	70	0.000004	0.000004
Chlordane	0.002	22	0.38	0.38
Carbon tetrachloride	0.005	0.15	1.9	0.15

1. From SESOIL model results (refer to Table 6).
2. From DETIER2 model results (refer to Table 7).
3. SAL that satisfies both groundwater-protection and direct-exposure concerns.

## RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 9. Generation of Tier 1 soil action levels: Drinking water source not threatened, rainfall  $\leq$  200cm/yr.

REFERENCE: HIDOH. 1995a. *Risk-Based Corrective Actions and Decision Making at Sites With Contaminated Soil and Groundwater*: State of Hawai'i Department of Health, Environmental Management Division.

Contaminant	Groundwater Action Level (mg/l)	<sup>1</sup> Groundwater -Protection SAL (mg/kg)	<sup>2</sup> Direct-Exposure SAL (mg/kg)	<sup>3</sup> TIER 1 Soil Action Level (mg/kg)
Acetone	0.61	5.8	3,000	5.8
Chlorobenzene	0.10	0.08	250	0.08
Chloroform	9.6	42	2.8	2.8
4,4 DDD	0.0006	120	1.8	1.8
4,4 DDE	0.014	530	1.3	1.3
4,4 DDT	0.000001	0.82	1.3	0.82
Di-n-octyl phthalate	0.73	31	1,300	31
Ethylene glycol	73,000	18,000	130,000	18,000
Methylene chloride	0.0043	0.003	42	0.003
PCBs (1260 Arochlor)	0.002	11	1	1
2,3,7,8 TCDD (Dioxin)	0.000003	70	0.000004	0.000004
Chlordane	0.0043	22	0.38	0.38
Carbon tetrachloride	12	232	1.9	1.9

1. From SESOIL model results (refer to Table 6).
2. From DETIER2 model results (refer to Table 7).
3. SAL that satisfies both groundwater-protection and direct-exposure concerns.



## RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 10. Generation of Tier 1 soil action levels: Drinking water source threatened, rainfall > 200cm/yr.

REFERENCE: HIDOH. 1995a. *Risk-Based Corrective Actions and Decision Making at Sites With Contaminated Soil and Groundwater*: State of Hawai'i Department of Health, Environmental Management Division.

Contaminant	Groundwater Action Level (mg/l)	<sup>1</sup> Groundwater -Protection SAL (mg/kg)	<sup>2</sup> Direct-Exposure SAL (mg/kg)	<sup>3</sup> TIER 1 Soil Action Level (mg/kg)
Acetone	0.61	0.06	3,000	0.06
Chlorobenzene	0.10	0.05	250	0.05
Chloroform	0.00016	0.0001	2.8	0.0001
4,4 DDD	0.0003	120	1.8	1.8
4,4 DDE	0.0002	530	1.3	1.3
4,4 DDT	0.0002	0.82	1.3	0.82
Di-n-octyl phthalate	0.73	31	1,300	31
Ethylene glycol	73,000	18,000	130,000	18,000
Methylene chloride	0.0043	0.002	42	0.002
PCBs (1260 Arochlor)	0.0005	11	1	1
2,3,7,8 TCDD (Dioxin)	4.5E-10	70	0.000004	0.000004
Chlordane	0.002	22	0.38	0.38
Carbon tetrachloride	0.005	0.024	1.9	0.024

1. From SESOIL model results (refer to Table 6).
2. From DETIER2 model results (refer to Table 7).
3. SAL that satisfies both groundwater-protection and direct-exposure concerns.

## RISK-BASED CORRECTIVE ACTION (HIDOH, 1995)

TABLE 11. Generation of Tier 1 soil action levels: Drinking water source not threatened, rainfall > 200cm/yr.

REFERENCE: HIDOH. 1995a. *Risk-Based Corrective Actions and Decision Making at Sites With Contaminated Soil and Groundwater*: State of Hawai'i Department of Health, Environmental Management Division.

Contaminant	Groundwater Action Level (mg/l)	<sup>1</sup> Groundwater -Protection SAL (mg/kg)	<sup>2</sup> Direct-Exposure SAL (mg/kg)	<sup>3</sup> TIER 1 Soil Action Level (mg/kg)
Acetone	0.61	0.06	3,000	0.06
Chlorobenzene	0.10	0.05	250	0.05
Chloroform	9.6	6.0	2.8	2.8
4,4 DDD	0.0006	120	1.8	1.8
4,4 DDE	0.014	530	1.3	1.3
4,4 DDT	0.000001	0.82	1.3	0.82
Di-n-octyl phthalate	0.73	31	1,300	31
Ethylene glycol	73,000	18,000	130,000	18,000
Methylene chloride	0.0043	0.002	42	0.002
PCBs (1260 Arochlor)	0.002	11	1	1
2,3,7,8 TCDD (Dioxin)	0.000003	70	0.000004	0.000004
Chlordane	0.0043	22	0.38	0.38
Carbon tetrachloride	12	58	1.9	1.9

1. From SESOIL model results (refer to Table 6).
2. From DETIER2 model results (refer to Table 7).
3. SAL that satisfies both groundwater-protection and direct-exposure concerns.

RISK-BASED CORRECTIVE ACTION AND DECISION MAKING AT SITES WITH  
CONTAMINATED SOIL AND GROUNDWATER

VOLUME II (APPENDICES)

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## APPENDIX A

### PREVIOUS SOIL CLEANUP CRITERIA (AUGUST, 1992, DOH-TGM)

**August 1992  
(First Edition)**

Table 5.1 DOH's Interim Recommended Cleanup Criteria for Soil and Water

CONSTITUENT		Above the UIC Line (Mauka) (Drinking Water Source)		Below the UIC Line (Makai) (Non-Drinking Water Source)	
		Water (ppm)	Soil (ppm)	Water (ppm)	Soil (ppm)
Volatile Organic Compounds	Benzene*	0.005	0.05	1.7	1.7
	Ethylbenzene	0.7	7.0	0.14	1.4
	Toluene	1.0	10.0	2.1	21.0
Semi-volatile and Non-volatile Organic Compounds	Benzo (a) pyrene*	0.0002	1.0	NS	1.0
	Acenaphthene	NS	100	0.320	100
	Fluoranthene	NS	500	0.013	500
	Naphthalene	NS	100	0.78	100
Metals	Lead (total)	0.05	400	0.14 *[.0056]*	400
	Cadmium (total)	0.005	2.0, or natural background (whichever is higher)	[0.0093]	2.0, or natural background (whichever is higher)
Halogenated Organic Compounds	Polychlorinated biphenyls* (PCB)	0.0005	1.0	[0.00003]	1.0
	1,1,1 Trichloroethane (1,1,1-TCA)	0.2	2.0	10.4	10.4
	Tetrachloroethylene* (PCE)	0.005	0.05	[0.145]	0.145

\* - Carcinogen; NS - No Standard; [ ] - Saltwater chronic surface water quality standard as established in Hawai'i Administrative Rules (HAR), Title 11, Chapter 54; \*[ ]\* - Currently proposed chronic standards in HAR 11-54 Revisions, April, 1992.

Note:

1. The recommended cleanup criteria for water at sites that are mauka of the UIC line are the existing or proposed MCL for that constituent. The recommended cleanup criteria for water at sites that are makai of the UIC line are based on the saltwater acute surface water quality standard (or chronic standard when available) as established in HAR Chapter 11-54.
2. The recommended cleanup criteria for volatile and halogenated organic compounds in soil at sites that are mauka of the UIC line are 10 times the existing or proposed MCL for that constituent with the exception of the criteria set for PCBs. The recommended cleanup criteria for PCBs in soil regardless of location are based on the required cleanup criteria for surface soils in non-restricted access areas as established under the Toxic Substances Control Act.
3. The recommended cleanup criteria for ethylbenzene and toluene in soil at sites that are makai of the UIC line is 10 times the saltwater acute surface water quality standards as established in HAR 11-54.
4. The recommended cleanup criteria for benzene, 1,1,1 TCA, and PCE in soil at sites that are makai of the UIC line are the same as the saltwater acute surface water quality standards (or chronic standards when available) as established in HAR 11-54 because of their degree of toxicity, pertinent physical and behavioral properties in the environment, and other health-related information.
5. The recommended cleanup criteria for semi-volatile and non-volatile organic compounds in soil regardless of their location relative to the UIC line are based on assessments of the physical and chemical characteristics of the compounds and the degradation, transformation, and toxicity of the constituents in the environment.
6. The recommended cleanup criteria for metals in soil regardless of their location relative to the UIC line are based on direct exposure to human and ecological receptors.
7. All sampling and analytical data intended to document or demonstrate that cleanup criteria (or other protective levels) have been attained should conform with appropriate field and laboratory quality assurance/quality control practices and should use appropriate methods for sample preparation, handling, and analysis. (See Section 7 on Sampling and Analysis.)

## **APPENDIX B**

**EXCERPTS FROM "THE NEW SESOIL USER'S GUIDE" AND "GROUNDWATER  
CONTAMINATION SUSCEPTIBILITY EVALUATION"**

# ***The New SESOIL User's Guide***

(Revision 1.6)  
August 1, 1994

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## Introduction Overview of the SESOIL Model

# 1

SESOIL is an acronym for Seasonal Soil Compartment Model and is a one-dimensional vertical transport code for the unsaturated soil zone. It is an integrated screening-level soil compartment model and is designed to simultaneously model water transport, sediment transport, and pollutant fate. The program was developed for EPA's Office of Water and the Office of Toxic Substances (OTS) in 1981 by Arthur D. Little, Inc. (ADL). ADL updated the SESOIL model in 1984 to include a fourth soil compartment (the original model included up to three layers) and the soil erosion algorithms (Bonazountas and Wagner, 1984). A comprehensive evaluation of SESOIL performed by Watson and Brown (1985) uncovered numerous deficiencies in the model, and subsequently, SESOIL was modified extensively by Hetrick et al. at Oak Ridge National Laboratory (ORNL) to enhance its capabilities (see Hetrick et al., 1986, 1988, 1989). The model is designed to be self-standing, but SESOIL was incorporated into a system called PCGEMS (Graphical Exposure Modeling System for the PC), a complete information management tool developed for EPA-OTS and designed to help users perform exposure assessments (General Sciences Corporation, 1987, 1989). Subsequently, PCGEMS was turned into the system called RISKPRO, which has numerous additions and improvements to PCGEMS, and is fully supported (General Sciences Corporation, 1990). The purpose of this document is to provide an up-to-date users manual for SESOIL as it is used in the RISKPRO system.

☐ **Side Note:**  
The SESOIL  
program is written  
in the FORTRAN  
language.

SESOIL was developed as a screening-level model, utilizing less soil, chemical, and meteorological values as input than most other similar models. Output of the SESOIL model includes time-varying pollutant concentrations at various soil depths and pollutant loss from the unsaturated zone in terms of surface runoff, percolation to the groundwater, volatilization, and degradation.

The SESOIL model accepts time-varying pollutant loading. For example, it is able to simulate chemical releases to soil from a variety of sources such as landfill disposal, accidental leaks, agricultural applications, leaking underground storage tanks, or deposition from the atmosphere. Other potential applications of SESOIL include long term leaching studies from waste disposal sites, pesticide and sediment transport on watersheds, studies of hydrologic cycles and water balances of soil compartments, and precalibration runs for other simulation models. One may also run the model to estimate the effect of various site management or design strategies on pollutant distributions and concentrations in the environment.

SESOIL can be used as a screening tool in performing exposure assessments. OTS used the model to predict the behavior of pollutants in soil compartments for analyzing and prioritizing chemical exposures. A number of studies have been conducted on the SESOIL model including sensitivity analysis, comparison with other models, and comparisons with field data (Bonazountas et al., 1982; Wagner

et al., 1983; Hetrick, 1984; Kincaid et al., 1984; Watson and Brown, 1985; Hetrick et al., 1986; Melancon et al., 1986; Hetrick et al., 1988; Hetrick et al., 1989). SESOIL has been applied in risk assessments concerning direct coal liquefaction (Walsh et al., 1984), incineration of hazardous waste (Holton et al., 1985; Travis et al., 1986), the transport of benzene to groundwater (Tucker et al., 1986), to soil cleanup levels in California (Odencrantz et al., 1991, 1992), and to site sensitivity ranking for Wisconsin soils for the Wisconsin Department of Natural Resources (Ladwig et al., 1992).

The soil column in SESOIL is a user-defined compartment extending from the surface through the unsaturated zone to the groundwater table. Typically, SESOIL is used to estimate the rate of migration of chemicals through soils and the concentration of the chemical in soil layers following chemical release to the soil environment. SESOIL's simulation of chemical persistence considers mobility, volatility, and degradation. The model performs calculations on an annual or monthly basis, and can simulate up to 99 years of chemical transport.

The model requires several types of chemical- and site-specific data to estimate the concentration of the chemical in the soil, its rate of leaching toward groundwater, and the impact of other environmental pathways. The user is required to provide chemical properties and release rate, and soil and climate data. This user's guide is designed to provide users of SESOIL with the information needed to efficiently and appropriately run the model and interpret the results. It provides a brief overview of how SESOIL can be used as an assessment tool. This document discusses the assumptions and equations used in the model and describes the use of SESOIL in the RISKPRO system, including details on how to build the input data files. A complete discussion of the output data file from SESOIL and the graphing capabilities available in the RISKPRO system is provided.

---

## 1.1 The RISKPRO System

The RISKPRO system simplifies data input by providing interactive prompts, parameter menus, and data retrieval programs in order for the user to extract pertinent data from on-line databases, create the input files required by SESOIL, run the model, and review and graph the model results.

---

☐ **Side Note:**  
*Although the math co-processor is not required, it is highly recommended since it substantially reduces computer time.*

The minimum system requirements for RISKPRO are:

- IBM XT/AT/PS2, 80386 or compatibles with 640 K RAM
- Hard Disk and 1 floppy disk drive
- DOS Version 2.2 or higher
- Graphics display adapter
- 540 K RAM available at all times
- 8087, 80287, or 80387 Math Co-processor.

## Exposure Assessment Overview

# 2

Concerns regarding actual and potential environmental pollution have made it necessary to know the fate and transport of chemicals entering the soil environment. For example, a synthetic, organic chemical may find its way into the soil and eventually to the groundwater from an unlined disposal site or a leaking underground storage tank. To better understand the possible impact of a chemical in the environment, one needs to develop a methodology that can predict where in the environment a chemical substance will be transported, and the rate and extent of its transformations.

In order to help define the impacts that chemical releases could have on the environment and human exposure, the SESOIL model can be used to perform an exposure assessment. In using the SESOIL model as an assessment tool, the first step involves information gathering. The essential information includes:

- ☐ the behavior of the chemical in the environment
- ☐ the rate and frequency of its release into the environment
- ☐ a description of the media in which the chemical is released.

In the SESOIL scenario, simulation of a chemical release to the land would include detailed information about the soil, the chemical, local weather patterns, and the underlying aquifers.

This manual will show the reader how to use the SESOIL model to determine the concentration of a chemical in various layers of the soil, including the surface layer. The SESOIL model can be used as an assessment tool to help the user estimate the volatilization of the chemical to the atmosphere, runoff rates, chemical concentrations in the soil column, and the rate of vertical migration (leaching) of a chemical toward groundwater, including quantities entering the groundwater.

## SESOIL Model Description

### 3

SESOIL is a one-dimensional vertical transport model for the unsaturated soil zone. SESOIL can consider only one compound at a time and the model is based on mass balance and equilibrium partitioning of the chemical between different phases (dissolved, sorbed, vapor, and pure). The SESOIL model was designed to perform long-term simulations of chemical transport and transformations in the soil. The model uses theoretically derived equations to represent water transport, sediment transport on the land surface, pollutant transformation, and migration of the pollutant to the atmosphere and groundwater. Climatic data, compartment geometry, and soil and chemical property data are the major components used in the equations.

The expression "long term" applies to both annual and monthly simulations in SESOIL, and is used in contrast to "short-term" models which employ a storm-by-storm resolution. Some soil models are designed to estimate pollutant distribution in the soil after each major storm event, and simulate chemical concentrations in the soil on a daily basis (e.g., see Patterson et al., 1984). These models are data intensive, requiring, for example, hourly rainfall input and daily maximum and minimum temperatures. SESOIL, on the other hand, estimates pollutant distribution in the soil column and on the watershed after a "season", which can be defined by the user as a year or a month. This is accomplished using a statistical water balance analysis and a washload routine statistically driven within the season. This approach saves time for the model user by reducing the amount of data that must be provided, and also reduces computer time and resource requirements since fewer computations are required.

☐ **Side Note:**  
*The SESOIL model is not data intensive.*

Two operation options are available for running SESOIL: annual estimates (Option A) requiring annual climatic data, and monthly estimates (Option M) requiring monthly data. It is recommended that the monthly option always be selected as it will provide a better estimate of chemical movement through the soil. RISKPRO simplifies the task of compiling monthly input data by extracting pertinent data from on-line databases (see the next section on building input data files using RISKPRO). Thus, the monthly option is no more difficult to use than the annual option. Option A is not available in the RISKPRO system, and this option will not be discussed further in this report with the exception of the hydrologic cycle, which implements the annual algorithm as described below. The annual option has not been changed from the original model, and those users interested in the annual option are referred to the report by Bonazountas and Wagner (1984).

The processes modeled by SESOIL are categorized into three cycles: hydrology, sediment, and pollutant transport. Each cycle is a separate sub-model within the SESOIL code. Most mathematical environmental simulation models may be categorized as stochastic or deterministic models. Both the stochastic and deterministic models are theoretically derived. Stochastic models incorporate the

concept of probability or some other measure of uncertainty, while deterministic models describe the system in terms of cause/effect relationships. SESOIL employs a stochastic approach for the hydrologic and washload cycles, and a deterministic approach for the pollutant transport cycle.

---

### 3.1 The Soil Compartment

In SESOIL, the soil compartment (or column) is a cell extending from the surface through the unsaturated zone to the upper level of the saturated soil zone, also referred to as the aquifer or groundwater table. While SESOIL estimates the pollutant mass added to the groundwater, the saturated zone is not modeled. The output from SESOIL can be used for generating input values for groundwater transport models. (In RISKPRO, the Analytic Transient 1-2-3 Dimensional Model, AT123D (Yeh, 1981), has been adapted to use SESOIL results for groundwater runoff (recharge) to simulate chemical movement in the saturated zone.)

---

☐ **Side Note:**  
Two to four layers and up to 40 sublayers, 10 in each layer, can be specified.

The soil compartment is treated differently by the hydrologic cycle and the pollutant cycle in SESOIL. In the hydrologic cycle, the whole soil column is treated as a single homogeneous compartment extending from the land surface to the water table. The pollutant cycle breaks the soil column into several compartments, also called layers. The layers in the pollutant cycle can be further broken up into sublayers. Each soil layer (sublayer) is considered as a compartment with a set volume and the total soil column is treated as a series of interconnected layers (sublayers). Each layer (sublayer) can receive and release pollutant to and from adjacent layers (sublayers).

The dimensions of the soil compartment are defined by the user. The width and length of the column are defined as the area of application of pollutant released to the soil, and the depth to the groundwater is determined from the thickness of user-defined soil layers that are used in the pollutant cycle. The soil column can be represented in 2, 3, or 4 distinct layers. Up to 10 sublayers can be specified for each layer, each having the same soil properties as the layer in which they reside.

There is no optimal size for the soil layers (sublayers); the dimensions of the soil column can be specified to cover any area from one square centimeter to several square kilometers. The area of the compartments is important for mass balance, but in terms of pollutant concentration the area of application is irrelevant since it is constant for all layers (sublayers). Note that the equations in SESOIL have been normalized to an area of one square centimeter.

It is suggested that the minimum depth of a layer is one centimeter. Depending on the application, layer depths can range from a shallow root zone of 5-25 centimeters, to a deep layer of more than 10 meters. When the pollutant enters a layer (sublayer), the model assumes instantaneous and uniform distribution of the chemical throughout that layer (sublayer). The model performs mass balance calculations over each entire soil layer (sublayer); there is no concentration gradient within a layer (sublayer). For a given amount of chemical released, the larger the layer (sublayer), the lower the calculated chemical concentration. For

this reason, SESOIL was discretized to allow as many as ten sublayers in each of the four possible major layers. Thus, the user may define as many as 40 smaller compartments using these sublayers. The result is an increase in the resolution of the model.

### 3.2 SESOIL Cycles

Pollutant transport and transformation in the unsaturated soil zone are complex processes affected by chemical, soil, and hydrogeological properties. In SESOIL, these processes are included in one of three cycles: the hydrologic cycle to deal with moisture movement or flow through the compartment, the sediment or washload cycle to deal with runoff from the soil surface, and the pollutant fate cycle. SESOIL was developed by integrating three submodels, one to deal with each cycle. The specific processes associated with each cycle are accounted for in the submodels. The cycles and their associated processes are summarized in Table 3.1 and Diagram 1 shows a schematic of the soil column.

The hydrologic cycle is done first in SESOIL, followed by the sediment cycle, and these results are used in the pollutant fate cycle. The hydrologic cycle is based on a statistical, dynamic formulation of a vertical water budget. It has been adapted to account for either yearly or monthly simulations and for moisture variations in the soil. The hydrologic cycle controls the sediment cycle, which is a theoretical monthly washload routine. The pollutant cycle simulates transport and transformation processes in three phases present in the soil compartment: soil-air or gaseous phase, soil-moisture phase, and adsorbed or soil-solids phase. The three major cycles are summarized in the sections that follow.

**Table 3.1**  
**SESOIL CYCLES**

#### *Hydrologic Cycle*

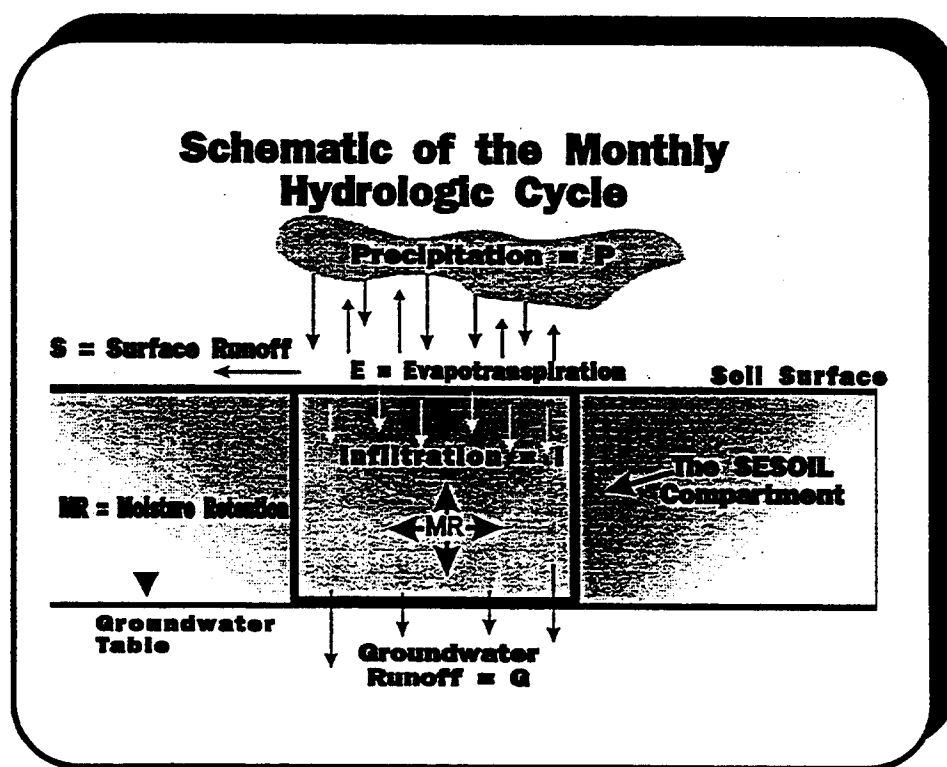
- Rainfall
- Groundwater runoff (recharge)
- Capillary rise
- Soil moisture retention (storage)
- Infiltration
- Surface runoff
- Evapotranspiration

#### *Sediment Cycle*

- Sediment washload (erosion due to storms)

#### *Pollutant Fate Cycle*

- Advection
- Diffusion (air phase)
- Sorption
- Washload
- Groundwater runoff (recharge)
- Chemical degradation/decay
- Cation exchange
- Volatilization
- Hydrolysis
- Surface runoff
- Metal complexation





### 3.3 Hydrologic Cycle

The hydrologic cycle is one-dimensional, considers vertical movement only, and focuses on the role of soil moisture (or interstitial pore water) in the soil compartment. The hydrologic cycle submodel calculates results for the hydrology of a site and passes these results to both the sediment washload cycle and the pollutant fate cycle. The hydrologic cycle used in SESOIL is an adaptation of the water balance dynamics theory of Eagleson (1978). The theory can be described as a dimensionless analytical representation of an annual water balance. It is itself a model based on simplified models of interacting hydraulic processes, including terms for the climate, soil, and vegetation. These processes are coupled through statistically based modeling.

It is beyond the scope of this manual to present the detailed physics and mathematical expressions of the model. The hydrologic cycle is thoroughly described by Eagleson (1978) and summarized by Bonazountas and Wagner (1984), and is based on the water balance equations shown below. All of these parameters are expected or mean annual values, and in SESOIL they are expressed in centimeters.

$$P - E - MR = S + G = Y \quad (1)$$

$$I = P - S \quad (2)$$

where:

- $P$  = precipitation
- $E$  = evapotranspiration
- $MR$  = moisture retention
- $S$  = surface runoff
- $I$  = infiltration
- $Y$  = yield
- $G$  = groundwater runoff or recharge  
(includes term for capillary rise)

Briefly, precipitation is represented by Poisson arrivals of rectangular gamma-distributed intensity pulses that have random depth and duration. Infiltration is

described by the Philip equation (Philip, 1969), which assumes the medium to be effectively semi-infinite, and the internal soil moisture content at the beginning of each storm and inter-storm period to be uniform at its long-term average. Percolation to the groundwater is assumed to be steady throughout each time step of simulation, at a rate determined by the long-term average soil moisture content. Capillary rise from the water table is assumed to be steady throughout the time period and to take place to a dry surface. The work of Penman (1963), Van den Honert (1948), and Cowan (1965) is employed in calculating evapotranspiration (Eagleson, 1978). Surface runoff is derived from the distribution of rainfall intensity and duration, and by use of the Philip infiltration equation. The effects of moisture storage are included in the monthly option in SESOIL, based on the work of Metzger and Eagleson (1980).

Eagleson's theory assumes a one-dimensional vertical analysis in which all processes are stationary in the long-term average. The expression "long term" applies to both annual and monthly simulations in SESOIL, and is used in contrast to "short-term" models which employ a storm-by-storm resolution. Also, Eagleson's approach assumes that the soils are homogeneous and that the soil column is semi-infinite in relation to the surface processes. Thus, in the hydrologic cycle of SESOIL, the entire unsaturated soil zone is conceptualized as a single layer (or compartment) and the prediction for soil water content is an average value for the entire unsaturated zone.

While the user can provide different permeability values as input for each of the four major soil layers for the pollutant cycle in SESOIL, the hydrologic cycle will compute and use the depth-weighted average permeability according to the formula:

$$K_z = \frac{d}{\sum_{i=1}^n \frac{d_i}{K_i}} \quad (3)$$

where:

- $K_z$  = vertically averaged permeability ( $\text{cm}^2$ ),
- $K_i$  = permeability for layer  $i$  ( $\text{cm}^2$ ),
- $d$  = depth from surface to groundwater (cm),
- $d_i$  = thickness of layer  $i$  (cm).

Thus, the user should exercise care when applying SESOIL to sites with large vertical variations in soil properties. The average permeability calculated by Eq. (3) in the hydrologic cycle may not be what the user intended and the resulting computed average soil moisture content may not be valid.

There is no explicit consideration of snow and ice, which are entered as precipitation. The model assumes that the water table elevation is constant with no change in groundwater storage from year to year. Bonazountas et al. (1984) adopted this theory for both annual and monthly simulations.

Each process in Eqs. (1) and (2) is written in terms of the soil moisture content, and solution of the equations is accomplished by iterating on soil moisture until the calculated value for precipitation is within 1.0% of the measured value input by the user. When this iteration is complete, the components such as infiltration, evapotranspiration, etc., in Eqs. (1) and (2) are known. SESOIL uses this procedure in both the annual and monthly routines. The monthly routine is an extension of the annual routine; both are discussed further below.

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### **3.3.1 Annual Cycle**

The annual water balance routine is based on Eagleson's (1978) theory. It encompasses one year, so multiple years have to be simulated as separate cycles. This routine simply determines the soil moisture content based on solution to equations (1) and (2) using annual climatic parameters. When the value for soil moisture content is arrived at through the iteration technique, the various processes described in equations (1) and (2) are known. Note that storage effects in the soil are not considered in the annual option. The theoretical basis for the annual dynamic hydrologic cycle used in SESOIL has been validated by Eagleson (1978). Annual model predictions were compared with empirical observations for five years of precipitation data at both a subhumid and arid climate location, with close agreement.

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### **3.3.2 Monthly Cycle**

The monthly water balance routine is based on the same theory as the annual routine, with modifications made to the details of moisture transfer from month-to-month (handling of moisture storage), and the radiation effects. The initial value for soil moisture content is calculated in SESOIL by summing the appropriate monthly climatic input data (for the first year) to obtain annual values and using the annual cycle algorithm. Then for each month, the monthly input values for precipitation, mean storm number, and mean length of the rain season are multiplied by 12 in order to again obtain "annual" values. Equations (1) and (2) are solved to compute the soil moisture content, and the results for the components (infiltration, evapotranspiration, etc.) are divided by 12 to attain average monthly values.

Note that if long-term average climatic data are used as input for each year (input for each month is the same from year to year), one would expect that the results for the hydrology for each month would be identical from year to year.

However, since the initial soil moisture content is computed as stated above for the first month (of the first year), this value will be different than the soil moisture calculated for the twelfth month that is then used for the first month of the following year. Thus, although hydrology results will not be identical for the first two years, they will be identical thereafter.

The monthly cycle in SESOIL does account for the change in moisture storage from month to month, incorporating the work of Metzger and Eagleson (1980). Also, the SESOIL evapotranspiration algorithm has been modified from the original work of Eagleson (1978) to include seasonal changes in average monthly radiation (radiation was a constant function of latitude before). Hetrick (1984) observed that hydrology predictions of the original SESOIL were insensitive to seasonal changes in meteorological data. To model the hydrology more realistically, an algorithm from the AGTEHM model (Hetrick et al., 1982) which computes daily potential radiation (incoming radiation for cloudless skies) for a given latitude and Julian date (December 31 = 365) is now used. The middle day of the month is used in the algorithm and the effect of cloud cover is calculated with the expression (Hetrick et al., 1982):

$$\bar{S} = S[(1 - C) + kC] \quad (4)$$

where:

- $\bar{S}$  = the average monthly radiation,
- $S$  = the potential radiation,
- $C$  = the fraction of sky covered by clouds, and
- $k$  = the transmission factor of cloud cover.

The value for  $k$  used in the model is 0.32, suggested by Hetrick et al. (1982). Since latitude and monthly cloud cover are required input for SESOIL, no new input data are needed to support this modification. There are now more pronounced monthly changes in evapotranspiration predictions (see Hetrick et al., 1986).

Although SESOIL does produce monthly results for soil moisture content of the root zone, defined in the model as the first 100 cm depth from the surface, this option has not been fully developed. Thus, values for soil moisture for the root zone will usually be identical to those for the entire soil column, and only very dry climates may cause a difference (M. Bonazountas, personal communication, 1986).

SESOIL model predictions (using the monthly option) of watershed hydrologic components have been compared with those of the more data intensive terrestrial ecosystem hydrology model AGTEHM (Hetrick et al., 1982) as well as to empirical measurements at a deciduous forest watershed and a grassland

watershed (see Hetrick et al., 1986). Although there were some differences in monthly results between the two models, good agreement was obtained between model predictions for annual values of infiltration, evapotranspiration, surface runoff, and groundwater runoff (recharge). Also, SESOIL model predictions compared well with the empirical measurements at the forest stand and the grassland watersheds.

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### 3.3.3 Hydrologic Model Calibration

Calibration of unsaturated soil zone models can be uncertain and difficult because climate, soil moisture, soil infiltration and percolation are strongly interrelated parameters that are difficult and expensive to measure in the field. However, if at all possible, input parameters for any unsaturated soil zone model should be calibrated so that hydrologic predictions agree with observations. In SESOIL, all input parameters required for the hydrologic cycle can be estimated from field studies with the exception of the pore disconnectedness index, "c". This parameter is defined as the exponent relating the "wetting" or "drying" time-dependent permeability of a soil to its saturated permeability (Eagleson, 1978; Eagleson and Tellers, 1982). Brooks and Corey (1966) presented the following relationship:

$$K(S) = K(1)S^c \quad (5)$$

where:

$K(1)$  = saturated hydraulic conductivity (cm/s),

$K(S)$  = hydraulic conductivity at  $S$  (cm/s),

$S$  = percent saturation,

$c$  = pore disconnectedness index.

Thus, this parameter is not commonly found in the literature. Default values for  $c$  suggested by Eagleson (1978) and Bonazountas and Wagner (1981, 1984) are: clay 12; silty clay loam 10; clay loam 7.5; silt loam 5.5; sandy loam 6; sandy clay loam 4; and sand 3.7. However, when data are available, this parameter should be varied first to optimize agreement between SESOIL results and hydrologic measurements. It should be noted that most unsaturated soil zone models require detailed data (which are difficult to obtain), such as soil moisture

characteristic curves. The "one variable" approach of Eagleson (1978) simplifies the data estimation process and reduces computational time.

Other sensitive parameters for the hydrologic cycle are the effective porosity and the intrinsic permeability (e.g., see Hetrick et al., 1986, 1989). While other parameters can be varied when calibrating the model to measured hydrologic data, it is recommended that the user vary the disconnectedness index first, followed by the permeability and/or porosity. See the section on input data for further details.

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### **3.4 Sediment Washload Cycle**

In pollutant transport models, estimates of erosion and sediment yield on watersheds may be needed in order to compute the removal of sorbed chemicals on eroded sediments. A major factor in this process is the surface runoff, rainwater which does not infiltrate the soil and may carry dissolved pollutant. Surface runoff is computed as part of the hydrologic cycle. Erosion is a function of the rate of surface runoff and several other factors. These factors include the impact of raindrops which detaches soil particles and keeps them in motion as overland flow, surface features such as vegetation and roughness, and infiltration capacity. Because of the difficulty in directly measuring washload using water quality monitoring techniques, estimation techniques and models are widely employed.

The sediment cycle of SESOIL is optional; it can be turned on or off by the user. Thus, if pollutant surface runoff is considered negligible, the washload cycle can be neglected. If the option is used, SESOIL employs EROS, a theoretical sediment yield model (Foster et al., 1980), which is part of the CREAMS model (Knisel, 1980; Foster et al., 1980). The erosion component considers the basic processes of soil detachment, transport, and deposition. The EROS model uses separate theoretically derived equations for soil detachment and sediment transport. Separate equations are needed for these two processes because the relationship of the detachment process to erosion is different than the relationship between erosion and transport.

For the detachment process, the model employs the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), modified by Foster et al. (1980) for single storm events. The USLE is applicable for predictions of annual sediment erosion originating mainly from small watersheds which are subject to sheet and rill erosion. Detachment of soil particles occurs when the sediment load already in the overland flow is less than the sediment capacity of this flow. The equation takes into account soil erodibility (the rate of soil loss per storm), which varies for different soil types and texture classes. The USLE considers topography, since both the length and the steepness of the land slope affect the rate of rain-induced soil erosion. Also, the land cover (e.g. vegetation) and the roughness of the soil surface affect the rate of erosion and the rate of overland transport. The USLE includes a parameter called "Manning's n", or roughness coefficient, to model these influences.

To model the sediment transport capacity for overland flow, EROS incorporates the Yalin Transport Equation (Yalin, 1963), modified for nonuniform sediment with a mixture of particle sizes and densities. The model estimates the distribution of sediment particles transported as sand, silt, and clay, and the fraction of organic matter in the eroded sediment. SESOIL computations of sediment transport are performed for each particle size type, beginning at the upper end of a slope and routing sediment downslope.

The EROS model in SESOIL accounts for several surface features which may divert and slow the overland flow, allowing settling and deposition of the washload. These include vegetation, which slows the flow and filters out particles, and topography, which includes surface characteristics such as roughness and the existence of small depressions. Change in slope and loss of water through infiltration into the soil will reduce the flow rate and encourage settling of soil particles. Organic matter is distributed among the particle types based on the proportion of primary clay in each type (Foster et al., 1980). Soil receiving the deposited sediment is referred to as enriched. EROS computes sediment enrichment based on the ratio of the surface area of the sediment and organic matter to that of the surface area of the residual soil (Knisel et al., 1983).

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### **3.4.1 Implementation In SESOIL**

The EROS model uses characteristic rainfall and runoff factors for a storm to compute erosion and sediment transport for that storm (Foster et al., 1980). Hydrologic input to the erosion component consists of rainfall volume, rainfall erosivity, runoff volume, and the peak rate of runoff for each storm event. These terms drive soil detachment and subsequent transport by overland flow. Note that input data for the hydrologic cycle of SESOIL include total monthly precipitation, the number of storms per month, and the mean time of each rainfall event. Since SESOIL provides only monthly estimates of hydrologic parameters and in order to couple the SESOIL and EROS models, a statistical method is used to generate the amount of rainfall and duration of each storm for every rainfall event during the month. This algorithm employs a model featuring probability distributions in order to estimate the individual storm parameters (Eagleson, 1978; Grayman and Eagleson, 1969).

The washload cycle has been implemented with two subroutines in addition to the EROS, model PARAM and STORM, which take the input data for and results generated by the hydrologic cycle and adapt them for use. The PARAM subroutine supports EROS by first retrieving the hydrologic input data (e.g. the number of storm events per month and the depth of rainfall) read by SESOIL and then setting specific parameters applicable to the STORM and EROS subroutines. The STORM subroutine then uses the PARAM results and statistically generates information about each storm using the algorithm mentioned above. Thus, the coupled SESOIL/EROS model does not require any additional hydrologic input parameters for individual storms. However, it should be recognized that estimates of rainfall for each storm may be quite different than the actual values.

Additional data needed for the sediment cycle include the washload area, the fraction of sand, silt and clay in the soil, the average slope and slope length of the representative overland flow profile, the soil erodibility factor, the soil loss ratio, the contouring factor, and Manning's n coefficient for soil cover and surface roughness. Example values for these parameters can be found in the CREAMS documentation (Knisel, 1980; Foster et al., 1980). Note that the washload area should be less than or equal to the pollutant application area.

EROS takes the information generated by both the PARAM and STORM subroutines and computes estimates of the sediment yield for each month. Information from the sediment cycle, along with information from the hydrologic cycle, is then provided to the pollutant fate cycle, which will be discussed in the next subsection.

The coupled SESOIL/EROS model was evaluated by comparing predictions to published measured data (Hetrick and Travis, 1988). Two cornfield watersheds and one grassland watershed were included in the study. The sites differed in their management practices, soil type, ground cover, and meteorology. The model predictions were in fair to good agreement with observed data from the three watersheds, except for months where surface runoff came from one or two high intensity storms (Hetrick and Travis, 1988).

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### **3.5 Pollutant Fate Cycle**

The pollutant fate cycle focuses on the various chemical transport and transformation processes which may occur in the soil. These processes are summarized in Table 3.1, and are discussed in more detail in the subsections that follow. The pollutant fate cycle uses calculated results from the hydrologic cycle and the sediment washload cycle. Information from these cycles is automatically provided to the pollutant fate cycle.

In SESOIL, the ultimate fate and distribution of the pollutant is controlled by the processes interrelated by the mass balance equation (6) below. The processes are selectively employed and combined by the pollutant fate cycle based on the chemical properties and the simulation scenario specified by the user. The actual quantity or mass of pollutant taking part in any one process depends on the competition among all the processes for available pollutant mass. Pollutant availability for participation in these processes, and the pollutant rate of migration to the groundwater, depends on its partitioning in the soil between the gas (soil air), dissolved (soil moisture), and solid (adsorbed to soil) phases.

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#### **3.5.1 Foundation**

In SESOIL, any layer (sublayer) can receive pollutant, store it, and export it to other subcompartments. Downward movement of pollutant occurs only with the soil moisture, while upward movement can occur only by vapor phase diffusion. Like the hydrologic cycle, the pollutant fate cycle is based on a mass balance



equation (Eq. 6) that tracks the pollutant as it moves in the soil moisture between subcompartments. Upon reaching and entering a layer or sublayer, the model assumes instantaneous uniform distribution of the pollutant throughout that layer or sublayer. The mass balance equation is:

$$O(t-1) + I(t) = T(t) + R(t) + M(t) \quad (6)$$

where:

- $O(t-1)$  = the amount of pollutant originally in the soil compartment at time  $t-1$  ( $\mu\text{g}/\text{cm}^2$ ),
- $I(t)$  = the amount of pollutant entering the soil compartment during a time step ( $\mu\text{g}/\text{cm}^2$ ),
- $T(t)$  = the amount of pollutant transformed within the soil compartment during the time step ( $\mu\text{g}/\text{cm}^2$ ),
- $R(t)$  = the amount of pollutant remaining in the soil compartment at time  $t$  ( $\mu\text{g}/\text{cm}^2$ ),
- $M(t)$  = the amount of pollutant migrating out of the soil compartment during the time step ( $\mu\text{g}/\text{cm}^2$ ).

The fate of the pollutant in the soil column includes both transport and transformation processes, which depend on the chemical's partitioning among the three phases: soil air, soil moisture, and soil solids. The three phases are assumed to be in equilibrium with each other at all times (see Diagram 2), and the partitioning is a function of user-supplied chemical-specific partition coefficients and rate constants. Once the concentration in one phase is known, the concentrations in the other phases can be calculated. The pollutant cycle of SESOIL is based on the chemical concentration in the soil water. That is, all the processes are written in terms of the pollutant concentration in soil water and the model iterates on the soil moisture concentration until the system defined by Eq. (6) balances.

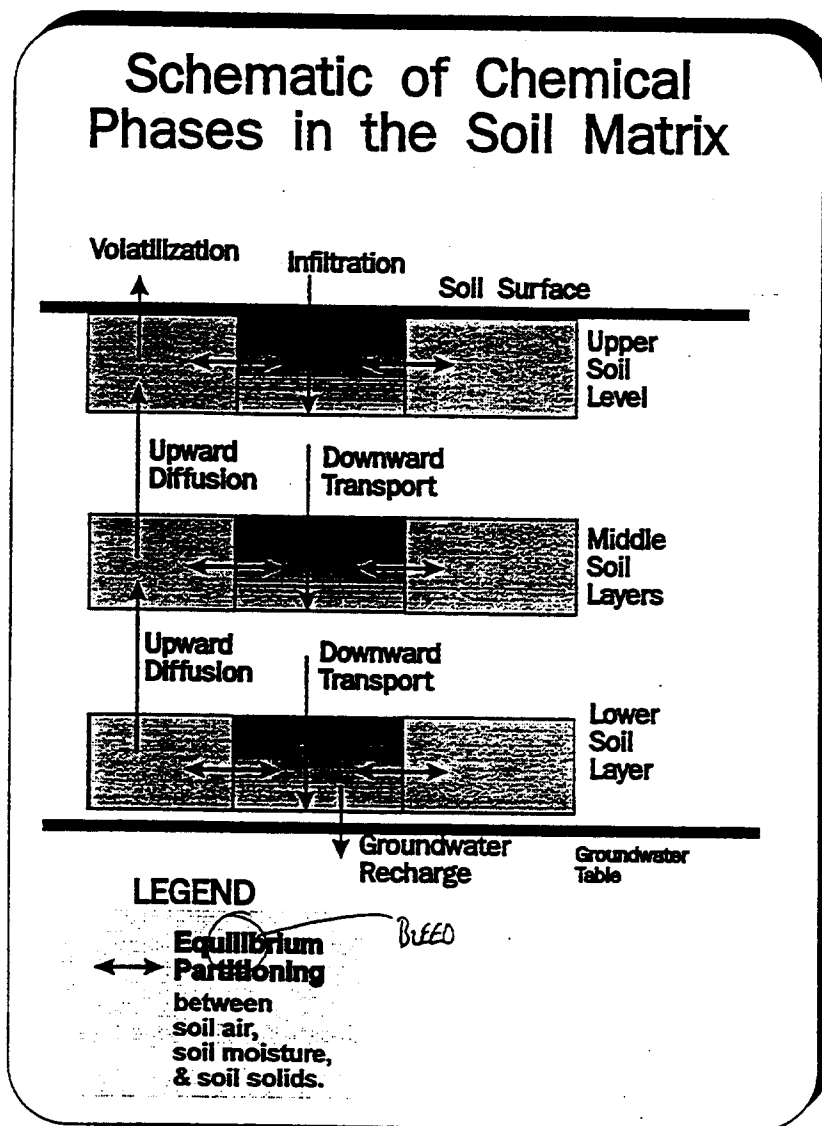


DIAGRAM 2

The concentration in the soil air is calculated via the modified Henry's law:

$$C_{sa} = \frac{cH}{R(T+273)} \quad (7)$$

where:

- $C_{sa}$  = pollutant concentration in soil air ( $\mu\text{g/mL}$ ),
- $c$  = pollutant concentration in soil water ( $\mu\text{g/mL}$ ),
- $H$  = Henry's law constant ( $\text{m}^3 \text{atm/mol}$ ),
- $R$  = gas constant [ $8.2 \times 10^{-5} \text{ m}^3 \text{atm/} (\text{mol } ^\circ\text{K})$ ], and
- $T$  = soil temperature ( $^\circ\text{C}$ ).

The concentration adsorbed to the soil is calculated using the Freundlich isotherm (note that a cation exchange option, discussed later, is available in SESOIL),

$$s = K_d c^{\frac{1}{n}} \quad (8)$$

where:

- $s$  = pollutant adsorbed concentration ( $\mu\text{g/g}$ ),
- $K_d$  = pollutant partitioning coefficient ( $\mu\text{g/g}/(\mu\text{g/mL})$ ),
- $c$  = pollutant concentration in soil water ( $\mu\text{g/mL}$ ), and
- $n$  = Freundlich exponent.

The total concentration of the pollutant in the soil is computed as:

$$c_o = f_a \cdot c_{sa} + \theta \cdot c + \rho_b s \quad (9)$$

where:

$c_o$  = overall (total) pollutant concentration ( $\mu\text{g}/\text{cm}^3$ ),

$f_a$  =  $f - \theta$  = the air-filled porosity (mL/mL),

$f$  = soil porosity (mL/mL),

$\theta$  = soil water content (mL/mL), and

$\rho_b$  = soil bulk density ( $\text{g}/\text{cm}^3$ ).

In SESOIL, each soil layer (sublayer) has a set volume and the total soil column is treated as a series of interconnected layers. Each layer (sublayer) has its own mass balance equation [Eq. (6)] and can receive and release pollutant to and from adjacent layers (sublayers). Again, the individual fate processes that compose the SESOIL mass balance equations (e.g., volatilization, degradation) are functions of the pollutant concentration in the soil water of each zone and a variety of first-order rate constants, partitioning coefficients, and other constants. An iterative solution procedure is used to solve the system (the iteration parameter is  $c$ ). See Bonazountas and Wagner (1984) for the numerical solution procedure.

The pollutant cycle equations are formulated on a monthly basis and results are given for each month simulated. However, to account for the dynamic processes in the model more accurately, an explicit time step of 1 day is used in the equations. The monthly output represents the summation of results from each day.

In the event that the dissolved concentration exceeds the aqueous solubility of the pollutant, the dissolved concentration is assumed to equal the aqueous solubility. That is, if during solution of the mass balance equation for any one layer, the dissolved concentration exceeds the solubility of the chemical, the iteration is stopped for that time step and the solubility is used as the dissolved concentration. The adsorbed and soil-air concentrations are calculated using the chemical partitioning equations as before [Eqs. (7) and (8)]. To maintain the mass balance, the remaining pollutant is assumed to remain in a pure phase (undissolved). Transport of the pure phase is not considered, but the mass of the chemical in the pure phase is used as input to that same layer in the next time step. Simulation continues until the pure phase eventually disappears. The pure

phase capability was not part of the original model and was added to SESOIL by Hetrick et al. (1989).

The discussion in the subsections that follow introduces the user to major algorithms and processes simulated in the pollutant cycle of SESOIL.

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### 3.5.2 The Pollutant Depth Algorithm

The pollutant cycle in SESOIL is based on the pollutant concentration in soil moisture. In theory, a non-reactive dissolved pollutant originating in any unsaturated soil layer will travel to another soil layer or to the groundwater at the same speed as the moisture mass originating in the same soil layer. The movement of a reactive pollutant however, will be retarded in relation to the movement of the bulk moisture mass due to vapor phase partitioning and the adsorption of the pollutant on the soil particles. If it is assumed that no adsorption occurs, and the vapor phase is negligible, the pollutant will move at the same rate as water through the soil.

Originally, only the advective velocity was used in SESOIL to determine the depth the pollutant reached during a time step. The depth (D) was calculated as

$$D = \frac{J_w t_c}{\theta} \quad (10)$$

where:

$J_w$  = water velocity (cm/s),

$t_c$  = advection time (s), and

$\theta$  = soil water content (cm<sup>3</sup>/cm<sup>3</sup>).

This approach allows all chemicals to reach the groundwater at the same time, irrespective of their chemical sorption characteristics. To account for retardation, SESOIL now uses the following equation to calculate the depth reached by a chemical with a linear equilibrium partitioning between its vapor, liquid, and adsorbed phases (Jury et al., 1984):

$$D = \frac{J_w t_c}{\theta + \rho_b K_d + \frac{f_a H}{R(T+273)}} \quad (11)$$

SESOIL calculates the flux  $J_w$  for each layer using the infiltration rate and groundwater runoff (recharge) rate computed by the hydrologic cycle, and the depths and permeabilities input by the user. Note that a different permeability can be input for each of the four major soil layers. While the hydrologic cycle will use the weighted mean average of layer permeabilities according to Eq. (3), the pollutant cycle does take into account the separate permeability for each layer in computing  $J_w$  at the layer boundaries according to the following equation:

$$J_{wz} = [G + (1 - G) \left( \frac{d_j}{d} \right)] \left( \frac{k_i}{K_z} \right) \quad (12)$$

where:

$J_{wz}$  = infiltration rate at depth  $z$ , which will be the boundary between two major layers (cm/s),

$G$  = groundwater runoff (recharge) (cm/s),

$I$  = infiltration at surface (cm/s),

$d_j$  = depth of soil column below depth  $z$  (cm),

$d$  = depth of soil column from surface to groundwater table (cm),

$K_z$  = intrinsic permeability defined by Eq. (3) (cm<sup>2</sup>), and

$k_i$  = the vertically-averaged permeability for layer  $i$  (cm<sup>2</sup>); is computed using Eq. (3) except  $d$  in the numerator of Eq. (3) is the sum of the layer depths above depth  $z$  and the summation in the denominator is from layer 1 to layer  $i$ .

The user is allowed two options for loading of pollutant: (1) a spill loading where all the pollutant is entered at the soil surface in the first time step of the month when the loading takes place, or (2) a steady application where the pollutant load is distributed evenly for each time step during the month at which the loading is specified. Option (1) allows loading at the soil surface only (layer 1, sublayer 1), whereas option (2) will allow loading in one or more of the four major layers. If sublayers are specified, the loading will always be entered into the first (top) sublayer of the major layer. Thus, while pollutant can be loaded in each of the four major layers, pollutant can not be loaded into each sublayer of a major layer to get a specific initial concentration distribution for the major layer.

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**Side Note:**

*Although a spill loading can not be used in SESOIL for layers 2, 3, or 4, an initial soil-sorbed concentration can still be approximated for these layers. See Section 4.5 for more information and Appendix A contains an example.*

If there is a spill loading or if the pollutant is entered as a steady application in layer 1 (sublayer 1), then the depth of the pollutant front is calculated using Eq. (11) starting from the surface. If a steady loading is specified in layers 2, 3, and/or 4, then the depth of the pollutant front is assumed to begin at the middle of the lowest layer at which pollutant is loaded (sublayer 1 of that layer if sublayers are included) and Eq. (11) is used to compute the depth of the pollutant front from that point. Subsequently, the pollutant is not allowed to enter a layer/sublayer until the depth of the pollutant front has reached the top of that layer/sublayer. When the pollutant depth reaches the groundwater table, pollutant leaves the unsaturated zone by simply multiplying the groundwater runoff (recharge) rate by the concentration in the soil moisture.

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### 3.5.3 Volatilization/Diffusion

In SESOIL, volatilization/diffusion includes movement of the pollutant from the soil surface to the atmosphere and from lower soil layers to upper ones. Note that vapor phase diffusion in SESOIL operates in the upward direction only. The rate of diffusion for a chemical is determined by the properties of the chemical, the soil properties, and environmental conditions. The volatilization/diffusion model in SESOIL is based on the model of Farmer et al. (1980) and Millington and Quirk (1961) and is a discretized version of Fick's first law over space, assuming vapor phase diffusion as the rate controlling process. That is, the same equation is used for volatilization to the atmosphere as is used for diffusion from lower layers to upper ones. The vapor phase diffusion flux through the soil  $J_v$  ( $\mu\text{g}/\text{cm}^2\text{s}$ ) is described as

$$J_a = -D_a \left( \frac{f_a^{\frac{10}{3}}}{f^2} \right) \frac{dc_{sa}}{dz} \quad (13)$$

where:

$D_a$  = the vapor diffusion coefficient of the compound in air ( $\text{cm}^2/\text{s}$ ), and

$c_{sa}$  = comes from Eq. (7) and  $f$  and  $f_a$  are as defined previously.

The volatilization algorithm in the original version of SESOIL allowed pollutant in the second (or lower) layer to volatilize directly to the atmosphere. This algorithm was modified by Hetrick et al. (1989). The pollutant can volatilize directly to the atmosphere from the surface layer, but if the chemical is in the second or lower layer, and the concentration in that layer is greater than the layer above it, then the chemical will diffuse into the upper layer rather than volatilize directly into the atmosphere.

An option the user has in the volatilization algorithm is to "turn off" the calculation by use of an input index parameter (for each layer). For example, if the index is set to 0.0 for each layer, the pollutant would not be allowed to diffuse upward or volatilize to the atmosphere; only downward movement of the pollutant with the soil moisture would occur. Also, if data are available, this index parameter can be varied to calibrate calculations to the measurements.

### **3.5.4 Sorption: Adsorption/Desorption And Cation Exchange**

SESOIL includes two partitioning processes for movement of pollutant from soil moisture or soil air to soil solids. These are the sorption process and the cation exchange mechanism.

The sorption process may be defined as the adhesion of pollutant molecules or ions to the surface of soil solids. Most sorption processes are reversible, adsorption describing the movement of pollutant onto soil solids and desorption being the partitioning of the chemical from solid into the liquid or gas phase (Lyman et al., 1982). Adsorption and desorption are usually assumed to be occurring in equilibrium and are therefore modeled as a single process (Bonazountas et al., 1984). Adsorption is assumed to occur rapidly relative to the migration of the pollutant in soil moisture; it can drastically retard pollutant migration through the soil column.



SESOIL employs the general Freundlich equation (see Eq. 8 above) to model soil sorption processes. The equation correlates adsorbed concentration with the dissolved concentration of the pollutant, by means of an adsorption coefficient and the Freundlich parameter. This equation has been found to most nearly approximate the adsorption of many pollutants, especially organic chemicals, and a large amount of data have been generated and are available in the literature (see Bonazountas and Wagner, 1984; Fairbridge and Finke, 1979; Lyman et al., 1982).

For most organic chemicals, adsorption occurs mainly on the organic carbon particles within the soil (Lyman et al., 1982). The organic carbon partition coefficient ( $K_{oc}$ ) for organic chemicals can be measured or estimated (Lyman et al., 1982).  $K_{oc}$  is converted to the partition coefficient ( $K_d$ ) by multiplying by the fraction of organic carbon in the soil.

Values for the Freundlich exponent can be found in the literature. They generally range between 0.7 and 1.1, although values can be found as low as 0.3 and as high as 1.7. In the absence of data, a value of 1.0 is recommended since no estimation techniques for this parameter have yet been developed. Note that using 1.0 for the Freundlich exponent assumes a linear model for sorption (see Eq. 8).

The user is cautioned regarding indiscriminately using literature values for the partition coefficient  $K_d$  or the Freundlich exponent  $n$ , or estimation methods for  $K_d$ . There can be much variability in the values that are estimated or found in the literature compared to actual measurements for a site. For examples, refer to the study of Melancon et al. (1986).

Another option for modeling adsorption in SESOIL uses cation exchange capacity (CEC). Cation exchange occurs when positively charged atoms or molecules (cations such as heavy metals) are exchanged with the cations of minerals and other soil constituents. CEC is a measure amount of cations per unit of soil that are available for exchange with the pollutant.

The cation exchange algorithm in SESOIL is very simple and estimates the maximum amount of pollutant that can be adsorbed. The calculation of the pollutant immobilized by cation exchange is given by (from Bonazountas and Wagner, 1984):

$$MCEC = a \cdot CEC \cdot MWT / VAL \quad (14)$$

where:

MCEC = maximum pollutant cation exchanged by the soil ( $\mu\text{g/g}$  soil),

a = 10.0 (units coefficient),

CEC = cation exchange capacity of the soil (meq/100 g of dry wt. soil),

MWT = molecular weight of the pollutant cation (g/mol),

VAL = valence of the cation (-).

**Side Note:**

The cation exchange algorithm has been verified to be computationally correct in SESOIL, but it has not been validated with measured data.

With clays, the exchanged ion is often calcium, and clay soils tend to have the highest cation exchange capacity. Note that the CEC value of a soil increases with increase in pH, but pH is not included in the CEC algorithm in SESOIL. The CEC value must be adjusted manually to include effects due to pH.

In SESOIL, cation exchange computed by Eq. 14 is assumed to occur instantaneously, and irreversibly. Once maximum adsorption via exchange has been reached, no additional adsorption will be calculated. The process is also assumed to take precedence over all other soil processes in competition for the pollutant cation.

The use of the cation exchange subroutine is optional. If it is used, Eq. (8) should not be used (i.e., model inputs for  $K_d$  and  $K_{oc}$  should be 0.0) unless the user has selected the model inputs in such a way as to avoid double accounting. It is up to the user to be sure that cation exchange is the predominant adsorption mechanism at the modeled site. This determination includes considerations of leachate characteristics such as pH, ionic strength, and the presence and concentration of other cations. The other cations, often found in landfill leachate and aqueous industrial wastes, may have higher affinity for exchange with soil cations, and may effectively block exchange between the pollutant and the soil cations. In addition, the speciation of the pollutant should be considered (Bonazountas and Wagner, 1984).

### 3.5.5 Degradation: Biodegradation And Hydrolysis

The pollutant cycle of SESOIL contains two transformation routines which can be used to estimate pollutant degradation in the soil. Biodegradation is the biologic breakdown of organic chemicals, most often by microorganisms. Hydrolysis is a chemical reaction of the pollutant with water. Both processes result in the loss of

the original pollutant and the creation of new chemicals. The SESOIL model accounts for the mass of original pollutant lost via degradation but does not keep track of any degradation products. The user is responsible for knowing what the degradation products will be and their potential significance.

The biodegradation process is usually a significant loss mechanism in soil systems since soil environments have a diverse microbial population and a large variety of food sources and habitats (Hamaker, 1972). Many environmental factors affect the rate of biodegradation in soil, including pH, moisture content of the soil, temperature, redox potential, availability of nutrients, oxygen content of the soil air, concentration of the chemical, presence of appropriate microorganisms, and presence of other compounds that may be preferred substrates. However, SESOIL doesn't consider these factors.

Biodegradation in SESOIL is handled as primary degradation, which is defined as any structural transformation in the parent compound which results in a change in the chemical's identity. It is estimated using the chemical's rate of decay in both the dissolved and adsorbed phases according to the first-order rate equation:

$$P_d = (C \cdot \theta \cdot k_{dl} + S \cdot p_b \cdot k_{ds}) \cdot A \cdot d_s \cdot \Delta t \quad (15)$$

where:

$P_d$  = decayed pollutant mass during time step  $\Delta t$  ( $\mu g$ ),

$k_{dl}$  = biodegradation rate of the compound in the liquid phase ( $day^{-1}$ ),

$k_{ds}$  = biodegradation rate of the compound in the solid phase ( $day^{-1}$ ),

$A$  = area of pollutant application ( $cm^2$ ),

$d_s$  = depth of the soil sublayer ( $cm$ ),

$\Delta t$  = time step ( $day$ ), and

$c$ ,  $\theta$ ,  $s$ , and  $p_b$  are as defined for Eqs. (8) and (9).

Note that  $c$ ,  $\theta$ , and  $s$  are functions of time in the SESOIL model.

The use of a first-order rate equation is typical for fate and transport models and generally is an adequate representation of biodegradation for many chemicals. However, due to the many factors affecting biodegradation, in some cases a first-order rate may not be applicable to the site field conditions and a zero-order or a second- or higher-order rate might be more appropriate. The biodegradation algorithm in SESOIL that is described by Eq. (15) can not handle these cases.

The user is cautioned regarding the use of literature values for the biodegradation rates since these values are quite variable and in many cases are not applicable to site field conditions. In most cases, biodegradation rates are very site-specific and uncertainty in these rates must be recognized. The user-supplied first-order decay rate constants (for moisture and solids) should be values measured for the pollutant in a soil culture test under conditions similar to the site being modeled.

The SESOIL hydrolysis algorithm allows the simulation of neutral, acid- or base-catalyzed reactions and assumes that both dissolved and adsorbed pollutant are susceptible to hydrolysis (Lyman et al., 1982). Since hydrolysis is the reaction of the pollutant with water, this reaction may occur at any depth as the pollutant moves through the soil column. The hydrolysis subroutine requires user-supplied rate constants for the neutral, acid and base hydrolysis reactions of the pollutant, and the pH for each soil layer. The model does not correct for the temperature of the modeled soil.

□ **Side Note:**  
The hydrolysis algorithm has been verified but has not been validated.

As for the biodegradation process, the algorithm for hydrolysis uses Eq. (15) except the rates  $k_d$  and  $k_{ds}$  are both replaced by the rate constant  $k_h$ , defined as (from Bonazountas and Wagner, 1984):

$$k_h = k_o + k_H [H^+] + k_{OH} [OH^-] \quad (16)$$

where:

- $k_h$  = the hydrolysis rate constant ( $\text{day}^{-1}$ ),
- $k_o$  = rate constant for neutral hydrolysis ( $\text{day}^{-1}$ ),
- $k_H$  = rate constant for acid-catalyzed hydrolysis ( $\text{days}^{-1}\text{mol}^{-1}\text{L}$ ),
- $[H^+]$  =  $10^{-\text{pH}}$ , the hydrogen ion concentration ( $\text{mol/L}$ ),
- $k_{OH}$  = rate constant for base-catalyzed hydrolysis ( $\text{days}^{-1}\text{mol}^{-1}\text{L}$ ), and
- $[OH^-]$  =  $10^{\text{pH}-14}$ , the hydroxyl ion concentration ( $\text{mol/L}$ ).

If cation exchange is considered, the following formula is used:

$$P_d = \text{MCEC} \cdot k_h \cdot p_b \cdot A \cdot d_s \cdot \Delta t \quad (17)$$

where the parameters are as defined for Eqs. (9), (14), (15), and (16).

Extrapolating hydrolysis rates measured in a laboratory to the environment increases the uncertainty of model results if the hydrolysis rate is not corrected for the influences of temperature, adsorption, the soil ionic strength, and the possible catalytic effect of dissolved material or solid surfaces. Since there are usually large uncertainties in hydrolysis rates, the SESOIL model results for hydrolysis should be considered only as approximations. The rate of hydrolysis for various organic chemicals may vary over more than 14 orders of magnitude. In addition, the hydrolysis routine does not consider the influence of ionic strength or the presence of other dissolved organics on the hydrolysis rate of the pollutant.

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☐ **Side Note:**  
The complexation routine has been verified but has not been validated.

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### 3.5.6 Metal Complexation

Complexation, also called chelation, is defined here as a transformation process. In SESOIL, complexation incorporates the pollutant as part of a larger molecule and results in the binding of the pollutant to the soil. For example, metal cations (e.g. copper, lead, iron, zinc, cadmium) combine with organic or other nonmetallic molecules (ligands) to form stable complexes. The complex that is formed will generally prevent the metal from undergoing other reactions or interactions of the free ion.

The pollutant fate cycle incorporates a simplified representation of the complexation process as a removal process. It is only available for scenarios in which the pollutant is a heavy metal. The model assumes a reversible process in which a metal ion is complexed by a specified soluble organic ligand to form a complex which is soluble, non-adsorbable, and non-migrating. Possible ligands are humic acid, fulvic acid, and low molecular weight carboxylic acids, which are commonly found in landfill leachate (Bonazountas and Wagner, 1984). It is the responsibility of the user to determine whether this process is likely to occur in the scenario being modeled, and to supply the appropriate information.

The complexation subroutine employs a nonlinear equation which must be solved numerically. It uses the same iterative procedure as the general pollutant cycle for monthly simulations. Required data include the stability (or dissociation) constant for the specific complex, and the mole ratio of ligand to metal. Also required are the molecular weights of the pollutant metal and the organic ligand. Equations used by this subroutine are based on the work of Giesy and Alberts (1984), Brinkman and Bellama (1978), and Sposito (1981). The model does not consider competition with metal ions in the soil which may have higher affinity for the ligand. Note that if the user chooses to model both cation exchange and metal complexation, the cation exchange process is assumed to occur first; ions involved in cation exchange are then unavailable for complexation. The general adsorption processes are modeled as being competitive with the complexation process (Bonazountas and Wagner, 1984).

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### 3.5.7 Pollutant In Surface Runoff And Washload

Pollutant can be removed from the soil area being simulated by SESOIL via surface runoff and washload. The pollutant in surface runoff is simply the surface runoff computed in the hydrologic cycle (for each month) multiplied by the pollutant concentration in the soil moisture of the surface layer (for each time step). The result of this calculation is multiplied by another user-supplied parameter called ISRM, which controls the amount of chemical partitioned into runoff. There is no basis for estimating ISRM a priori; it can be set to 0.0 to "turn off" the pollutant participation in runoff, or it can be used essentially as a fitting parameter if data are available. In a calibration/validation exercise used to predict atrazine runoff at a site in Watkinsville, Georgia, the parameter ISRM was found to be 0.06 (see Hetrick et al., 1989).

Pollutant loss via washload is computed by taking the sediment yield from the washload cycle multiplied by the adsorbed pollutant concentration in the surface layer. While studies have been conducted comparing results of sediment yield with field data (Hetrick and Travis, 1988), pollutant loss via washload has not been validated in SESOIL.

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### 3.5.8 Soil Temperature

The original SESOIL model assumed that soil temperature was equal to the user-supplied air temperature. The model was modified by Hetrick et al. (1989) to predict soil temperature from air temperature according to the following (Toy et al., 1978):

$$\text{Summer: } Y = 16.115 + 0.856X,$$

$$\text{Fall: } Y = 1.578 + 1.023X,$$

$$\text{Winter: } Y = 15.322 + 0.656X,$$

$$\text{Spring: } Y = 0.179 + 1.052X,$$

where:

$Y$  = the mean monthly soil temperature (°F).

$X$  = the mean monthly air temperature (°F).

These regression equations are very crude and not depth dependent. However, further complexity is not warranted since soil temperature is used only in Eq. (7) and does not significantly affect results. It should be noted that some chemical parameters and processes are dependent on temperature (for example, solubility,

Henry's law constant, and rate constants for biodegradation and hydrolysis). No explicit consideration of these effects is included in SESOIL, and the user should adjust the input values for such parameters if temperature effects are judged to be important.

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### **3.5.9 Pollutant Cycle Evaluation**

There are several approaches used to evaluate the reliability and usefulness of an environmental model, such as verification, calibration, sensitivity analysis, uncertainty analysis, and validation. Verification establishes that results from each of the algorithms of the model are correct. Calibration is the process of adjusting selected model parameters within an accepted range until the differences between model predictions and field observations are within selected criteria of performance (Donnigan and Dean, 1985). Sensitivity analysis focuses on the relative impact each parameter or term has on the model output, in order to determine the effect of data quality on output reliability. Uncertainty analysis seeks to quantify the uncertainty in the model output as a function of uncertainty in both model input and model operations. Validation also compares measured with predicted results, but includes analysis of the theoretical foundations of the model, focusing on the model's performance in simulating actual behavior of the chemical in the environment under study. (Note that the term validation has often been broadly used to mean a variety of things, including all five of the techniques mentioned above.)

A number of calibration, validation, and sensitivity studies have been performed on the SESOIL model. The model has been verified by extensive testing using extreme ranges of input data. Studies of the hydrologic and washload cycles have already been discussed above (see Sections 3.3 and 3.4). The following discusses the kinds of evaluations that have been performed on the pollutant cycle of the SESOIL model. Note that model validation is a continuing process; no model is ever completely validated.

To assess SESOIL's predictive capabilities for pollutant movement, a pollutant transport and validation study was performed by Arthur D. Little, Inc. under contract to EPA (Bonazountas et al., 1982). The application/validation study was conducted on two field sites, one in Kansas and one in Montana. SESOIL results were compared to data for the metals chromium, copper, nickel, and sodium at the Kansas site and the organics naphthalene and anthracene at the Montana site. Results showed reasonable agreement between predictions and measurements, although the concentrations of the metals were consistently underestimated, and the rate of metal movement at the Kansas site was consistently overestimated. At the Montana site, the concentrations of the organics were overestimated by SESOIL. Bonazountas et al. (1982) state that the overestimations for the organics were probably due to the fact that biodegradation was not considered in the simulations. Note that this study was done with the original SESOIL model, not the modified model that is described herein.

Hetrick et al. (1989) compared predictions of the improved version of SESOIL with empirical data from a laboratory study involving six organic chemicals (Melancon et al., 1986) and from three different field studies involving the application of aldicarb to two field plots (Hornsby et al., 1983; R. L. Jones, 1986; Jones et al., 1983, 1985) and atrazine to a single-field watershed (Smith et al., 1978). Results for several measures of pollutant transport were compared including the location of chemical peak vs. time, the time-dependent amount of pollutant leached to groundwater, the depth distribution of the pollutant at various times, the mass of the chemical degraded, and the amount of pollutant in surface runoff. This study showed that SESOIL predictions were in good agreement with observed data for both the laboratory study and the field studies.

SESOIL does a good job of predicting the leading edge of the chemical profile (Hetrick et al., 1989), due mainly to the improvement of the pollutant depth algorithm to include the chemical sorption characteristics (see Section 3.5.2 above). Also, when a split-sample calibration/validation procedure was used on 3 years of data from the single-field watershed, SESOIL did a good job of predicting the amount of chemical in the runoff. The model was less effective in predicting actual concentration profiles; the simulated concentrations near the soil surface underestimated the measurements in most cases. One explanation is that SESOIL does not consider the potential upward movement of the chemical with the upward movement of water due to soil evaporation losses.

SESOIL is a useful screening-level chemical migration and fate model. The model is relatively easy to use, the input data are straightforward to compile, and most of the model parameters can be readily estimated or obtained. Sensitivity analysis studies with SESOIL can be done efficiently. SESOIL can be applied to generic environmental scenarios for purposes of evaluating the general behavior of chemicals. Care should be taken when applying SESOIL to sites with large vertical variations in soil properties since the hydrologic cycle assumes a homogeneous soil profile. Only one value for the soil moisture content is computed for the entire soil column. If different permeabilities are input for each soil layer, the soil moisture content calculated in the hydrologic cycle using the vertically-averaged permeability (Eq. 3) may not be valid for the entire soil column. Thus, the user is warned that even though the model can accept different permeabilities for each layer, the effects of variable permeability are not fully accounted for by the model.

It is recommended that predictions for the hydrology at a given site be calibrated to agree with known measurements. Caution should be used when making conclusions based on modeling results when little hydrologic data exist against which to calibrate predictions. In these cases, it is recommended that the user employ sensitivity analysis or evaluate results obtained by assigning distributions to the input parameters (e.g., see Gardner, 1984; O'Neill et al., 1982; Hetrick et al., 1991). However, when properly used, SESOIL is an effective screening-level tool in assessing chemical movement in soils.



**GROUNDWATER CONTAMINATION  
SUSCEPTIBILITY EVALUATION  
SESOIL MODELING**

Final Report  
May 3, 1993

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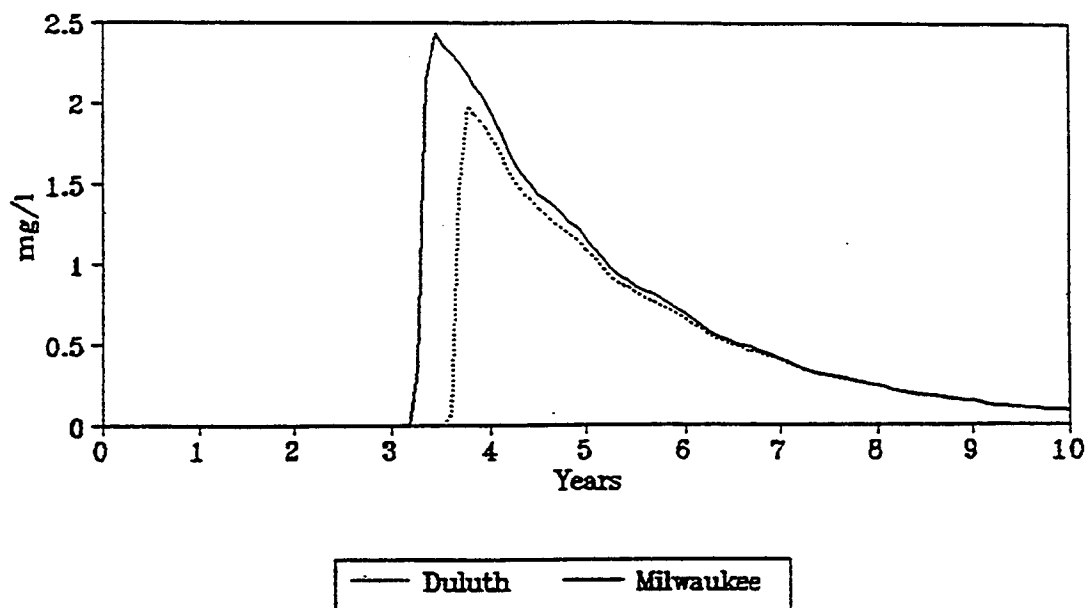
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# LAYER 4: BENZENE CONCENTRATIONS (SAND) Climate

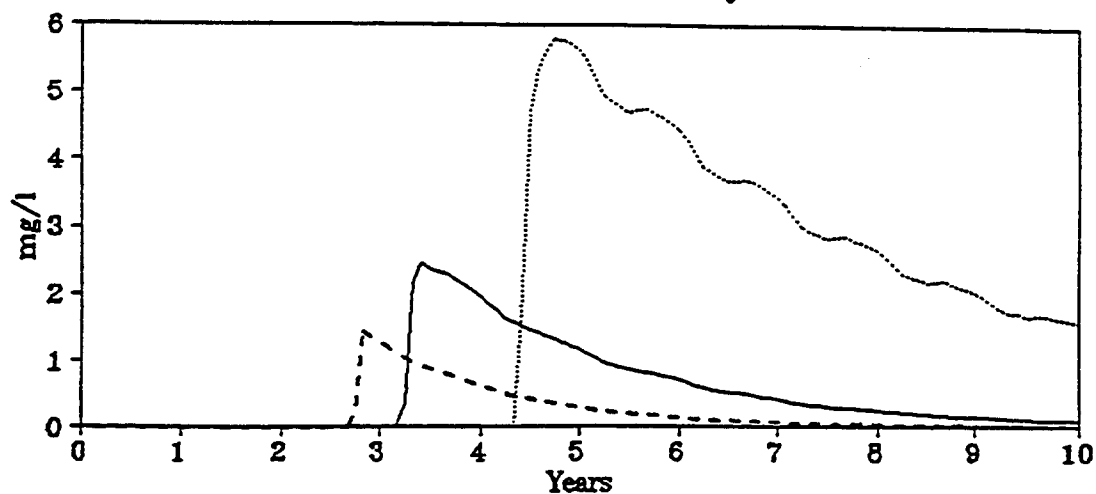


Climate	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
Milwaukee	2.4	-	93 %
Duluth	2.0	0.83	94 %

C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout038

Figure B-1

# **LAYER 4: BENZENE CONCENTRATIONS (SAND)** Intrinsic Permeability

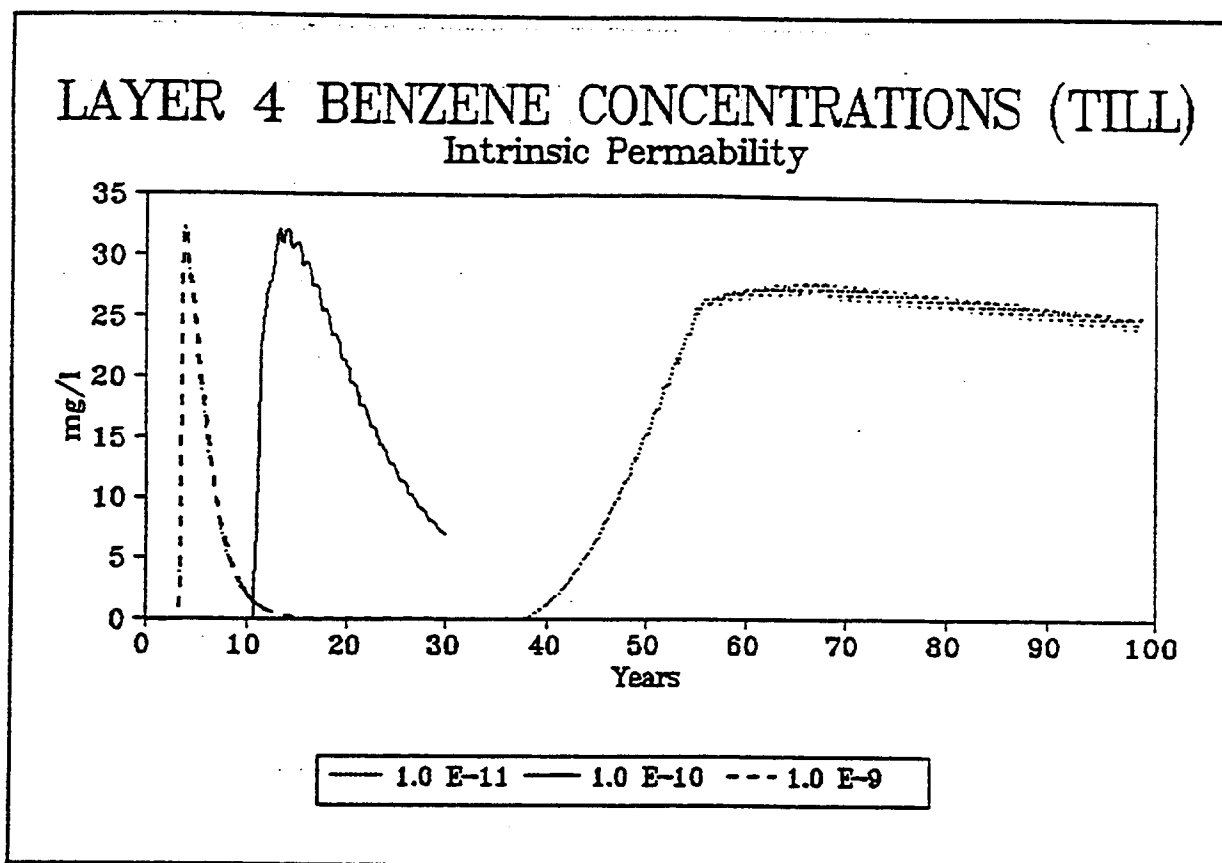


— 1.0 E-9 — 1.0 E-8 ---- 1.0 E-7

Intrinsic Permeability cm <sup>2</sup>	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1.0 E-9	5.8	2.4	75 %
1.0 E-8	2.4	-	93 %
1.0 E-7	1.4	0.58	96 %

C:\1sesoil\benzene\ssout010, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout011

Figure B-2

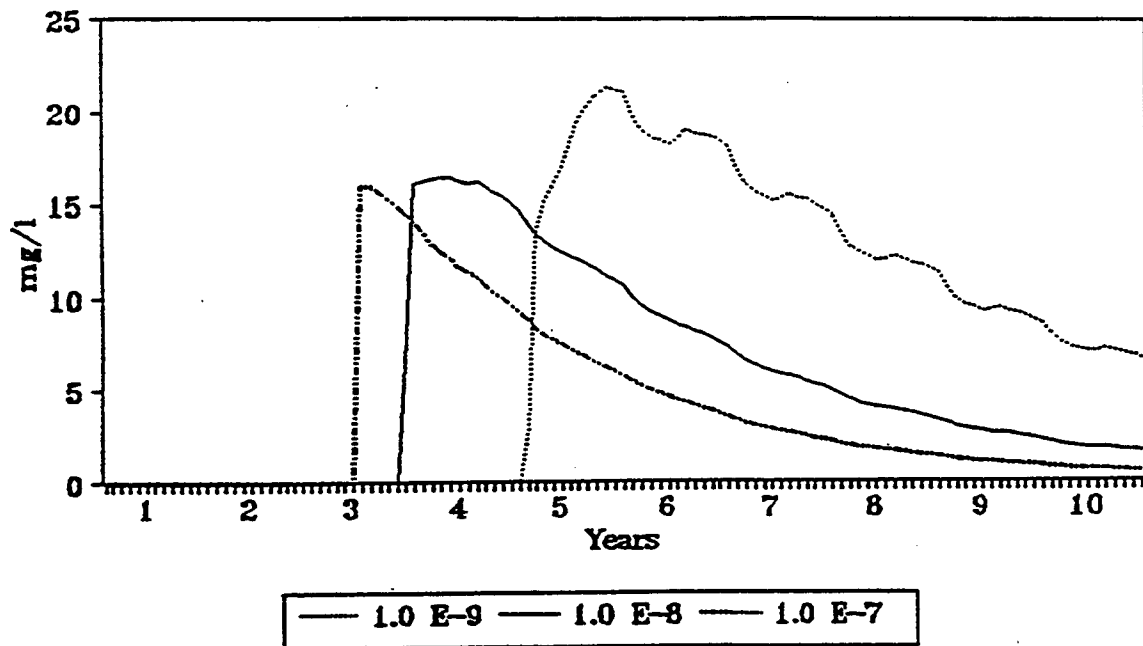


Intrinsic Permeability cm <sup>2</sup>	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1.0 E-11	28	0.88	1.8 %
1.0 E-10	32	-	4.1 %
1.0 E-9	32	1.0	25 %

C:\2sesoil\benzene\ssout014, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout022

Figure B-3

# LAYER 4 DCA CONCENTRATIONS (SAND) Intrinsic Permeability

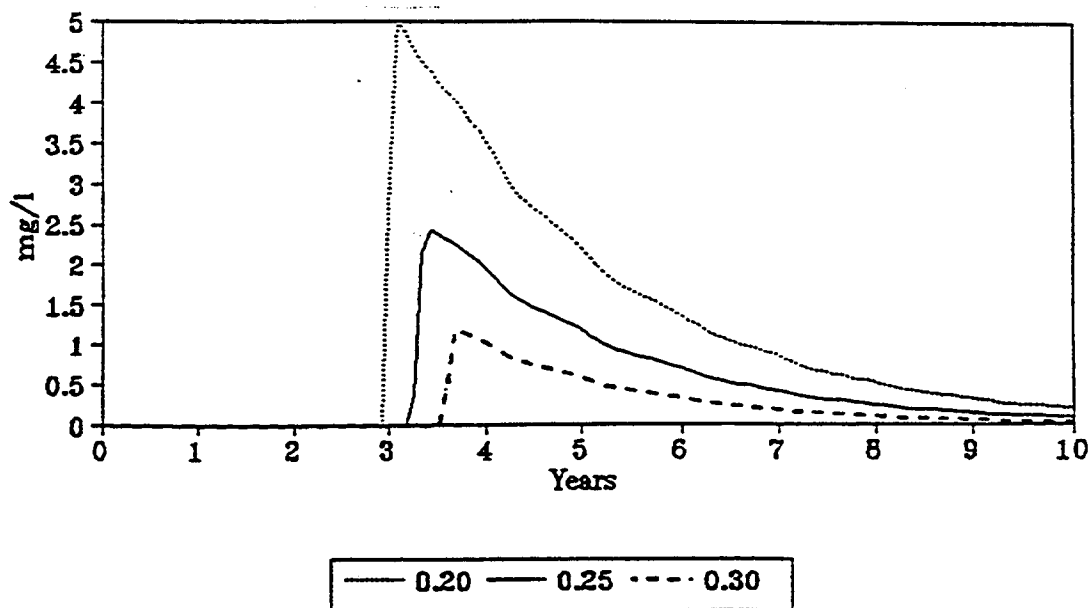


Intrinsic Permeability cm <sup>2</sup>	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1.0 E-9	21	1.3	11 %
1.0 E-8	16	-	25 %
1.0 E-7	16	1.0	35 %

c:\2sesoil\dca\ssout016, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout017

Figure B-4

# LAYER 4: BENZENE CONCENTRATIONS (SAND) Porosity

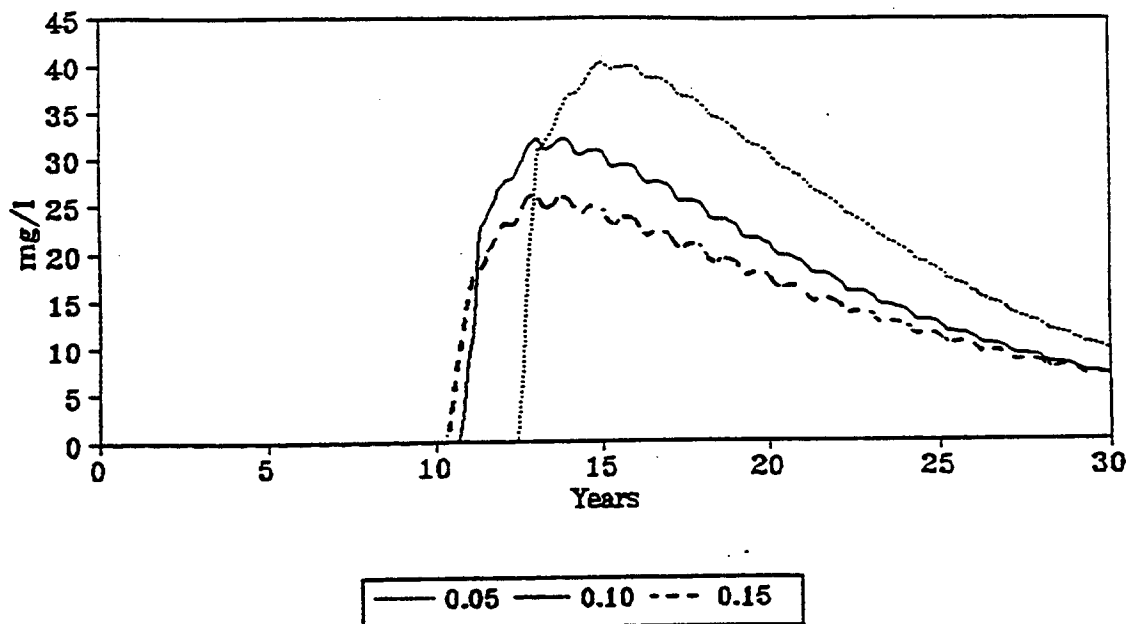


Effective Porosity	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.20	5.0	2.1	83 %
0.25	2.4	-	93 %
0.30	1.2	0.50	97 %

C:\1sesoil\benzene\ssout012, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout013

Figure B-5

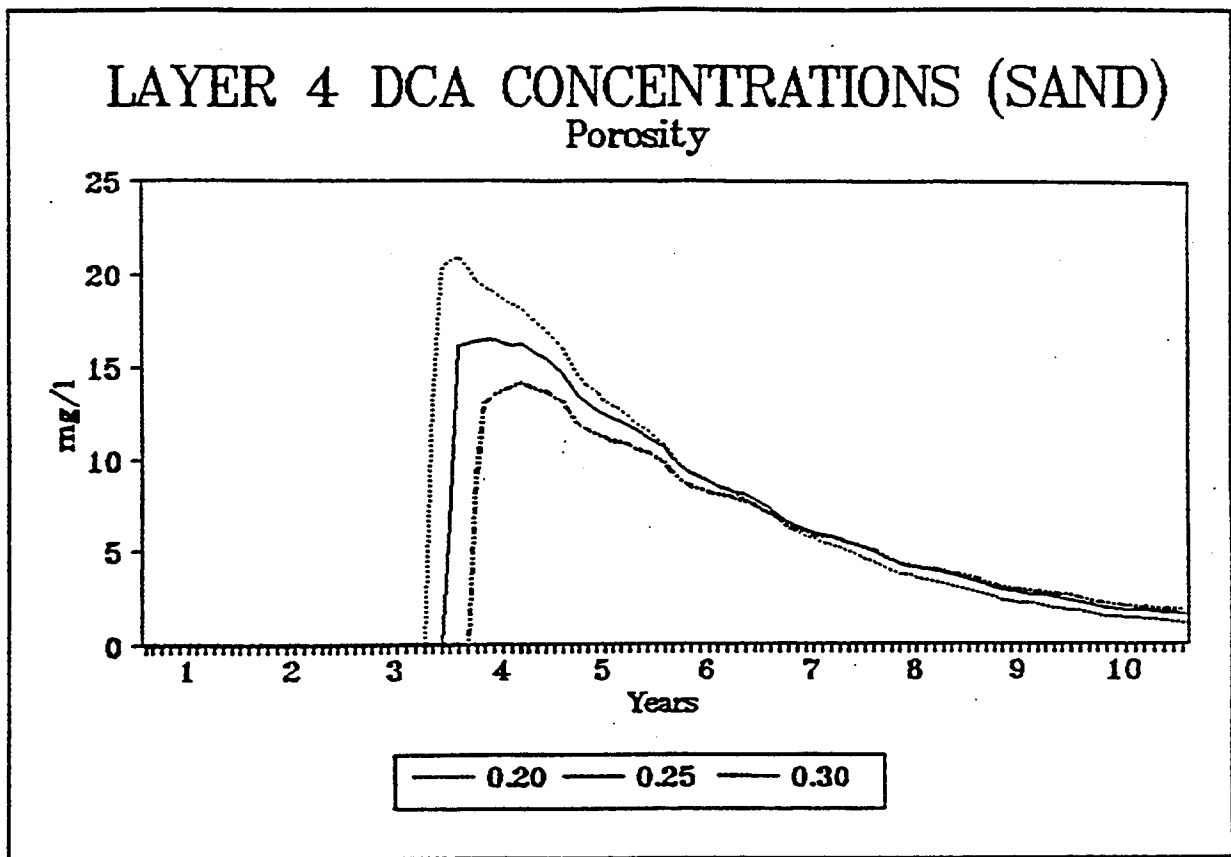
# LAYER 4 BENZENE CONCENTRATIONS (TILL) Porosity



Effective Porosity	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.05	40	1.2	1.6 %
0.10	32	-	4.1 %
0.15	26	0.81	7.8 %

C:\2sesoil\benzene\ssout015, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout016

Figure B-6



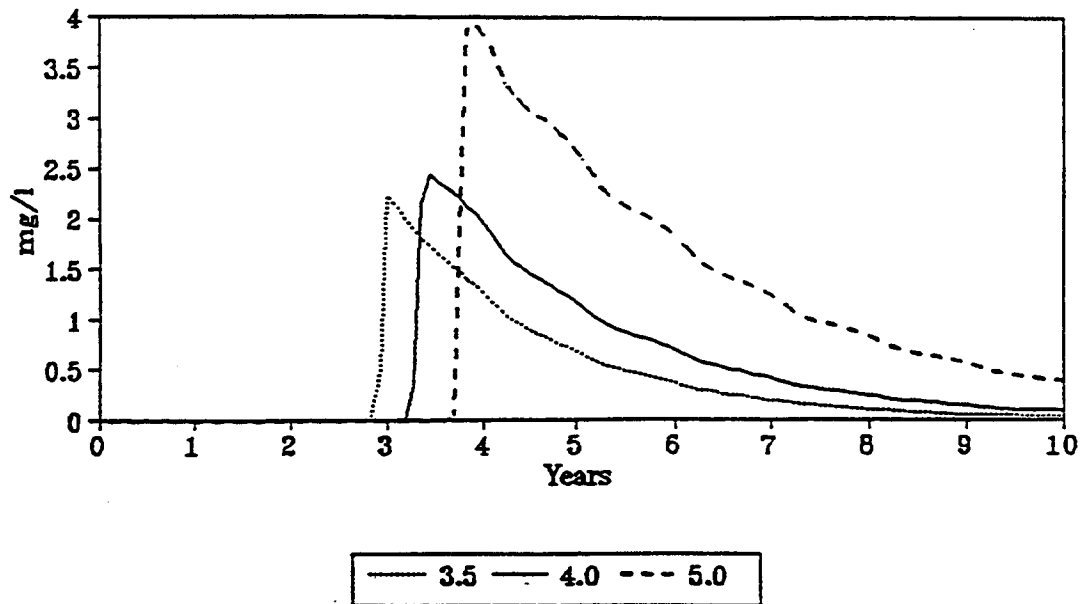
Porosity	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.20	21	1.3	15 %
0.25	16	-	25 %
0.30	14	0.88	35 %

c:\2sesoil\dca\ssout018, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout019

Figure B-7



# **LAYER 4: BENZENE CONCENTRATIONS (SAND)** Soil Disconnectedness



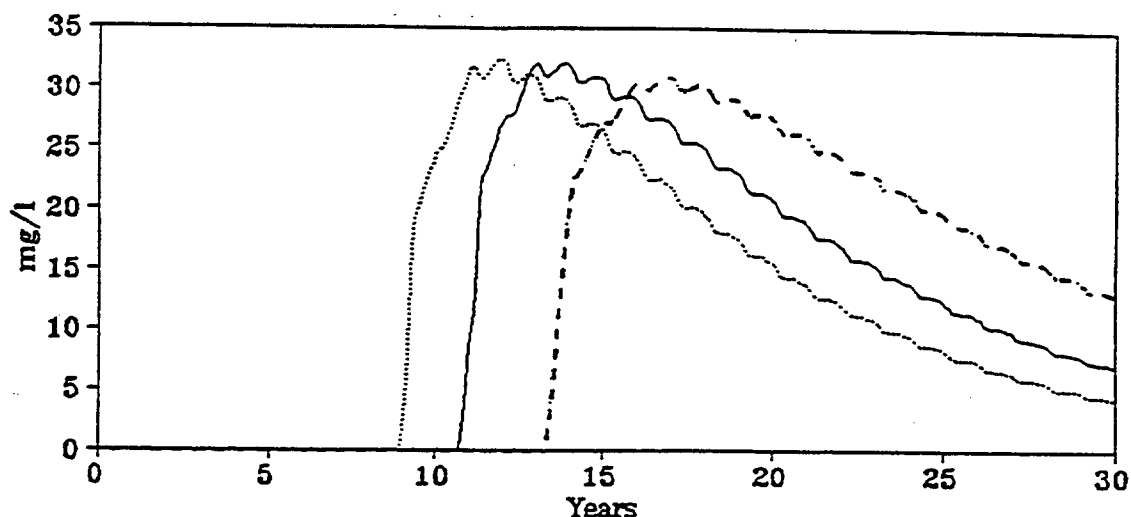
Soil Disconnectedness	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
3.5	2.2	0.92	94 %
4.0	2.4	-	93 %
5.0	3.9	1.6	86 %

C:\1sesoil\benzene\ssout021, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout020

Figure B-8

# LAYER 4 BENZENE CONCENTRATIONS (TILL)

Soil Disconnectedness

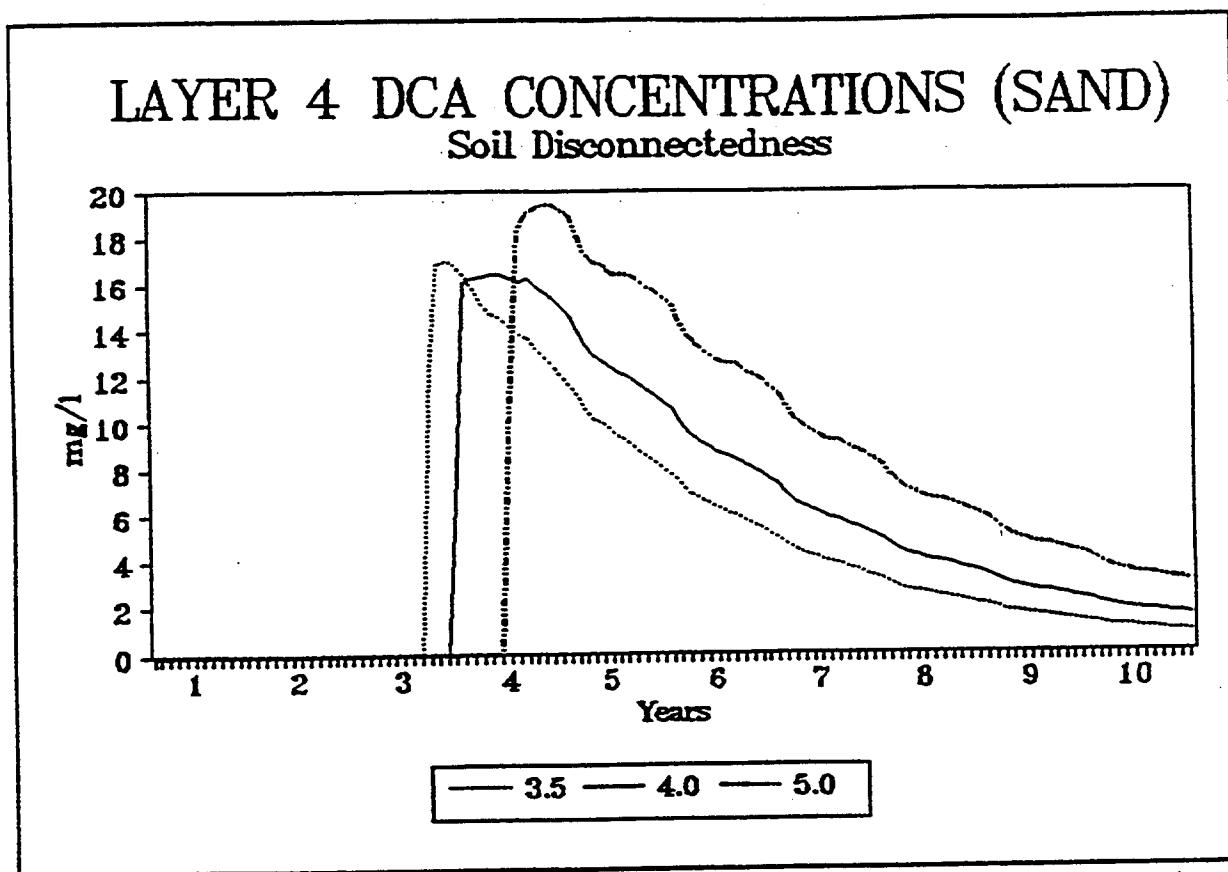


— 7.0 — 8.0 - - - 9.0

Soil Disconnectedness	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
7.0	32	1.0	4.4 %
8.0	32	-	4.1 %
9.0	31	0.97	4.4 %

C:\2sesoil\benzene\ssout017, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout018

Figure B-9

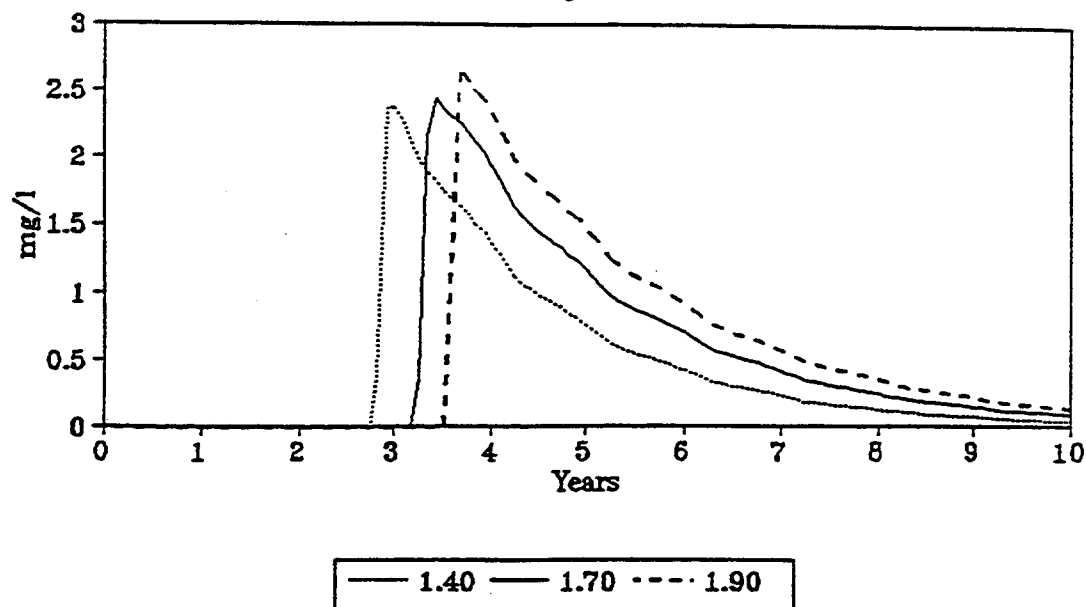


Soil Disconnectedness	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
3.5	17	1.1	28 %
4.0	16	-	25 %
5.0	19	1.2	17 %

c:\2sesoil\dca\ssout020, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout021

Figure B-10

# **LAYER 4: BENZENE CONCENTRATIONS (SAND)** Bulk Density Scenarios

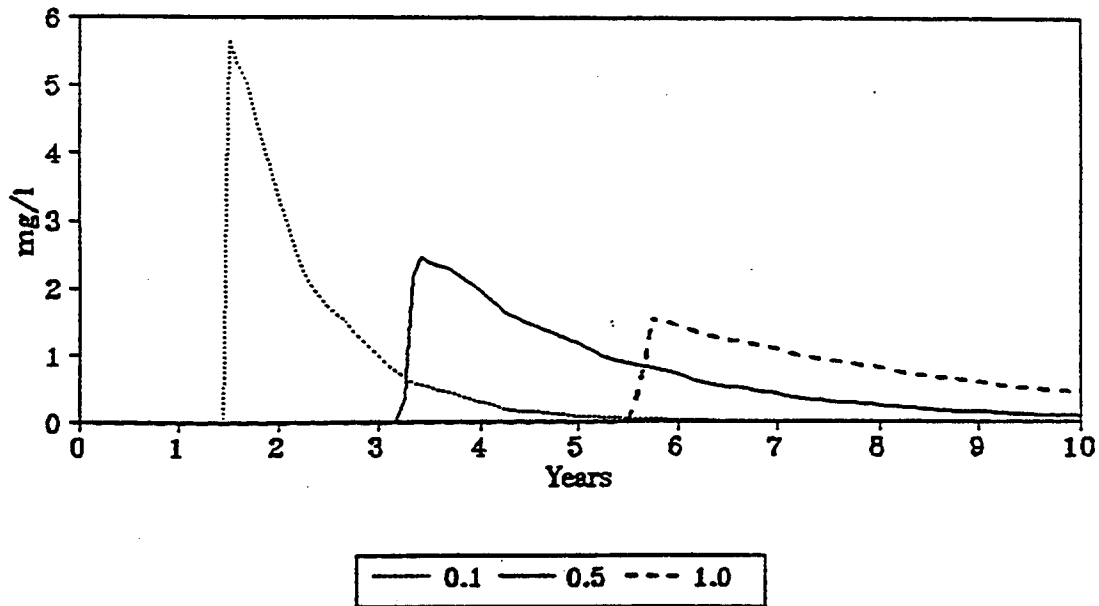


Bulk Density Scenarios g/cm <sup>3</sup>	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1.40	2.4	1.0	93 %
1.70	2.4	-	93 %
1.90	2.7	1.1	93 %

C:\1sesoil\benzene\ssout067, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout068

Figure B-11

# **LAYER 4: BENZENE CONCENTRATIONS (SAND)** Percent Organic Carbon Content

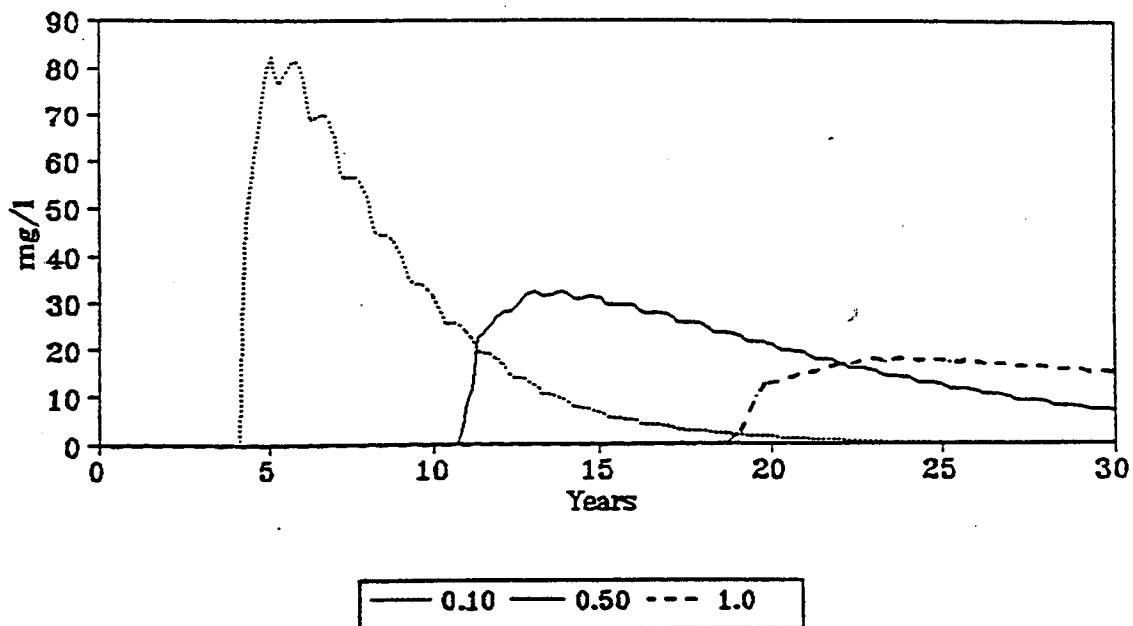


Percent Organic Carbon Content	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.10 %	5.7	2.4	93 %
0.50 %	2.4	-	93 %
1.00 %	1.5	0.62	90 %

C:\1sesoil\benzene\ssout022, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout023

Figure B-12

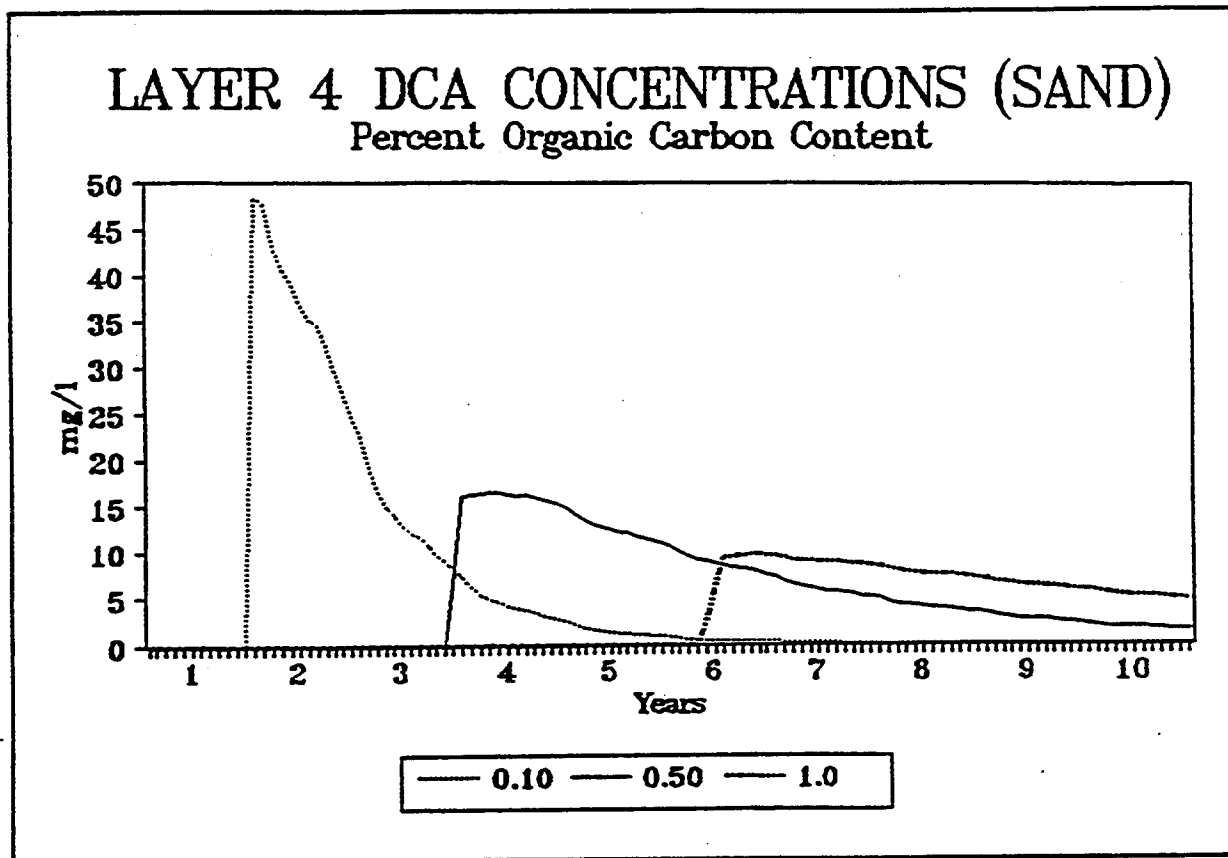
# LAYER 4 BENZENE CONCENTRATIONS (TILL) Percent Organic Carbon Content



Percent Organic Carbon Content	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.10 %	83	2.6	4.1 %
0.50 %	32	-	4.1 %
1.00 %	13	0.41	3.9 %

C:\2sesoil\benzene\ssout019, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout020

Figure B-13

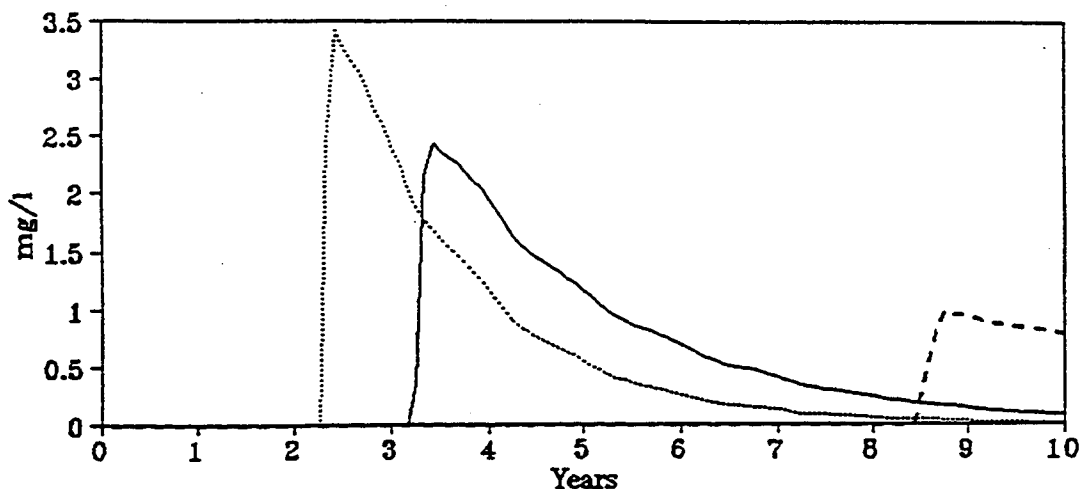


Percent Organic Carbon Content	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.1 %	48	3.0	25 %
0.5 %	16	-	25 %
1.0 %	9.7	0.61	23 %

c:\2sesoil\dca\ssout022, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout023

Figure B-14

# LAYER 4: BENZENE CONCENTRATIONS (SAND) Organic Carbon Adsorption Coefficient



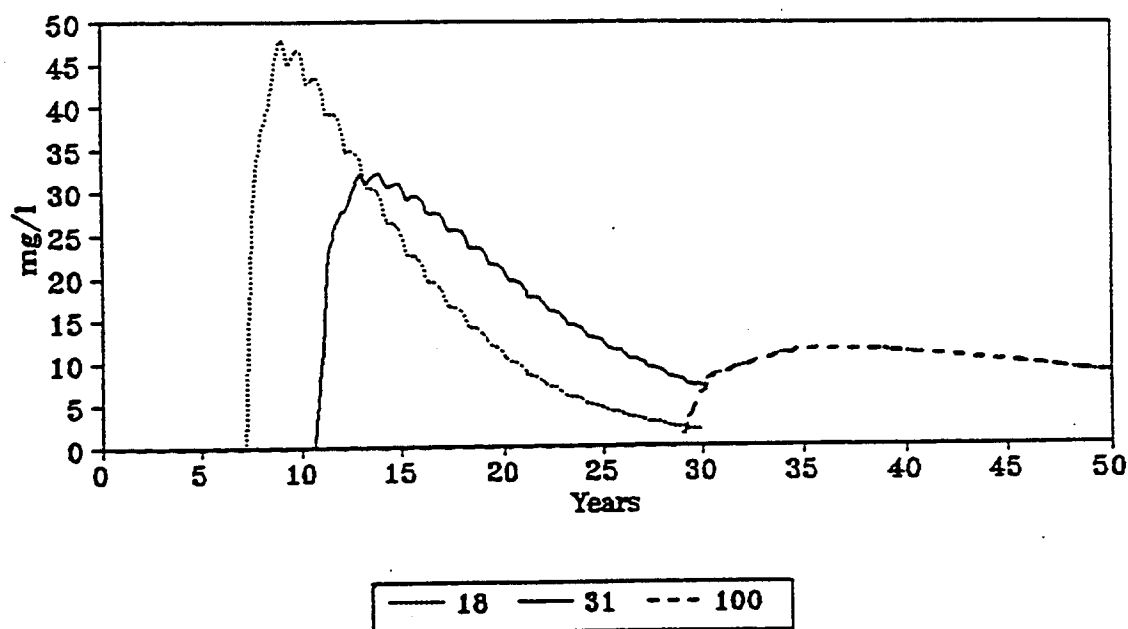
Organic Carbon Adsorption Coefficient $K_{oc}$ (ug/g)/(ug/ml)	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
18	3.4	1.4	93 %
31	2.4	-	93 %
100	0.97	0.40	86 %

C:\1sesoil\benzene\ssout026, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout027

Figure B-15



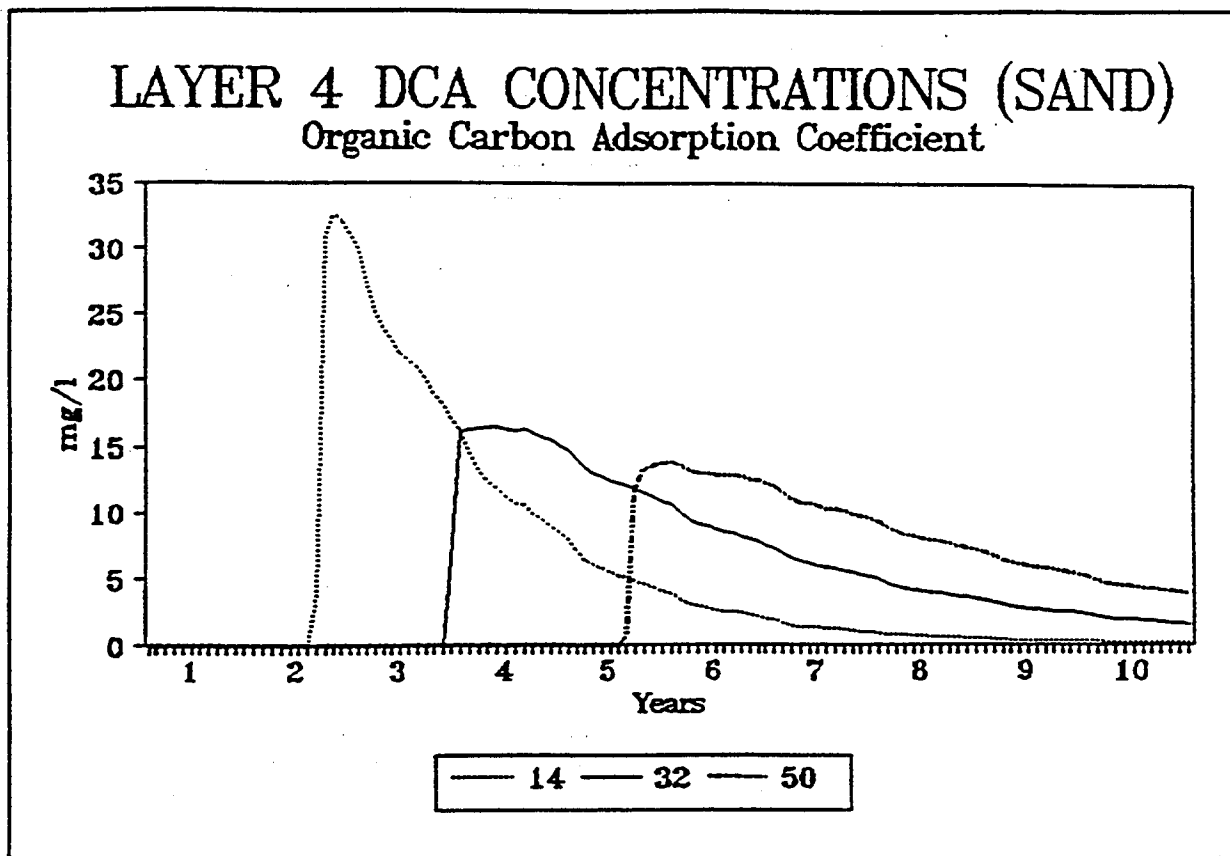
# LAYER 4 BENZENE CONCENTRATIONS (TILL) Organic Carbon Adsorption Coefficient



Organic Carbon Adsorption Coefficient $K_{oc}$ (ug/g)/(ug/ml)	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
18	48	1.5	4.1 %
31	32	-	4.1 %
100	11	0.34	3.9 %

C:\2sesoil\benzene\ssout037, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout038

Figure B-16



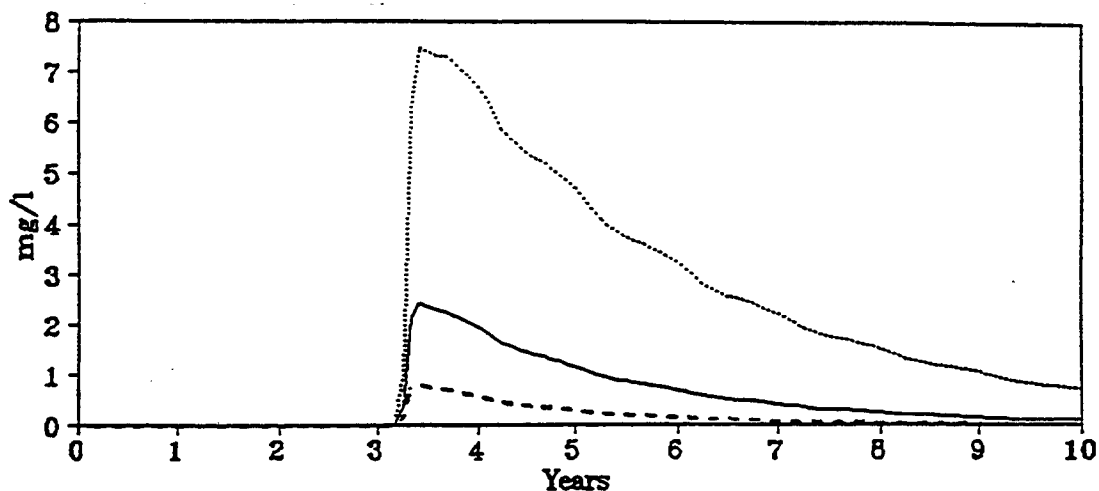
Organic Carbon Adsorption Coefficient K <sub>oc</sub> (ug/g)/(ug/ml)	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
14	33	2.0	25 %
32	16	-	25 %
50	12	0.75	24 %

c:\2sesoil\dca\ssout024, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout025

Figure B-17

# LAYER 4: BENZENE CONCENTRATIONS (SAND)

Air Diffusion Coefficient



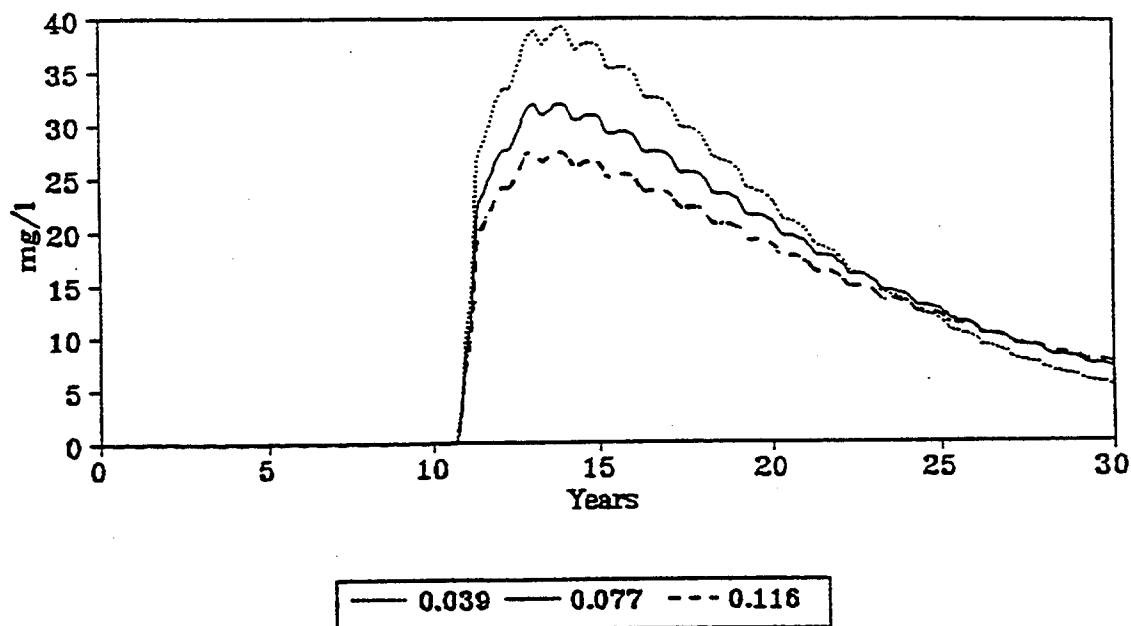
— 0.039 — 0.077 --- 0.116

Air Diffusion Coefficient cm <sup>2</sup> /sec	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.039	7.5	3.1	68 %
0.077	2.4	-	93 %
0.116	0.80	0.33	98 %

C:\1sesoil\benzene\ssout030, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout031

Figure B-18

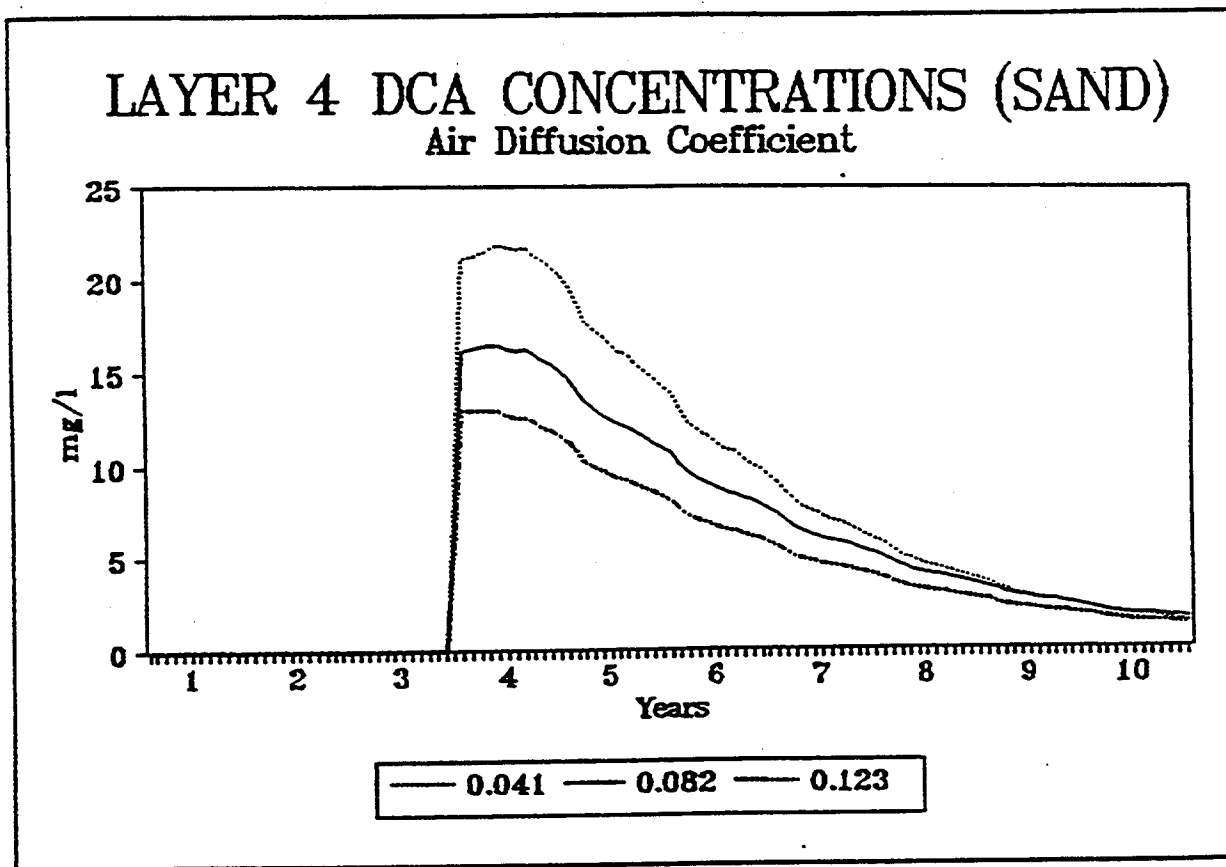
# LAYER 4 BENZENE CONCENTRATIONS (TILL) Air Diffusion Coefficient



Air Diffusion Coefficient (cm <sup>2</sup> /sec)	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.039	39	1.2	1.1 %
0.077	32	-	4.1 %
0.116	28	0.9	8.6 %

C:\2sesoil\benzene\ssout023, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout024

Figure B-19

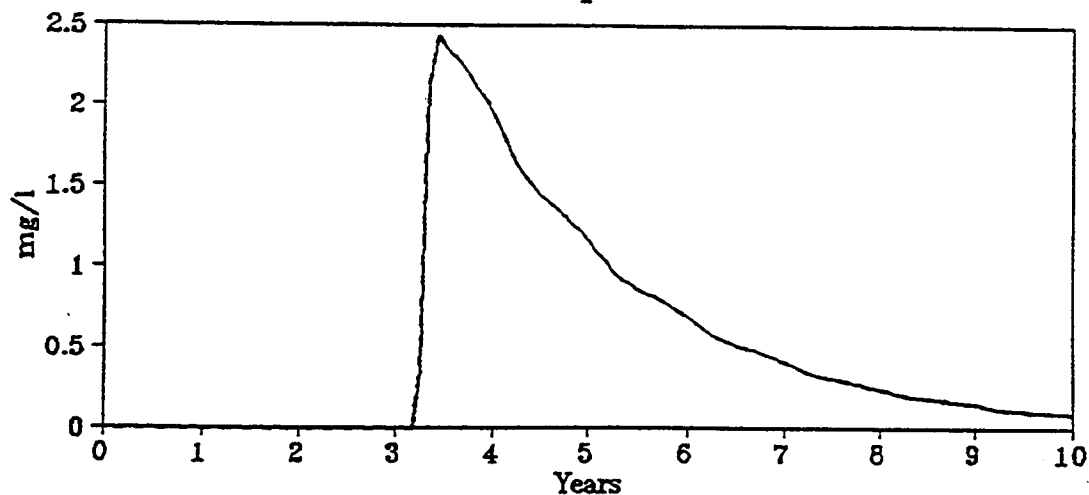


Air Diffusion Coefficient cm <sup>2</sup> /sec	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0.041	22	1.4	8.5 %
0.082	16	-	25 %
0.123	13	0.81	41 %

c:\2sesoil\dca\ssout028, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout029

Figure B-20

# LAYER 4: BENZENE CONCENTRATIONS (SAND) Soil pH



— 5.5 — 6.5 - - - 7.5

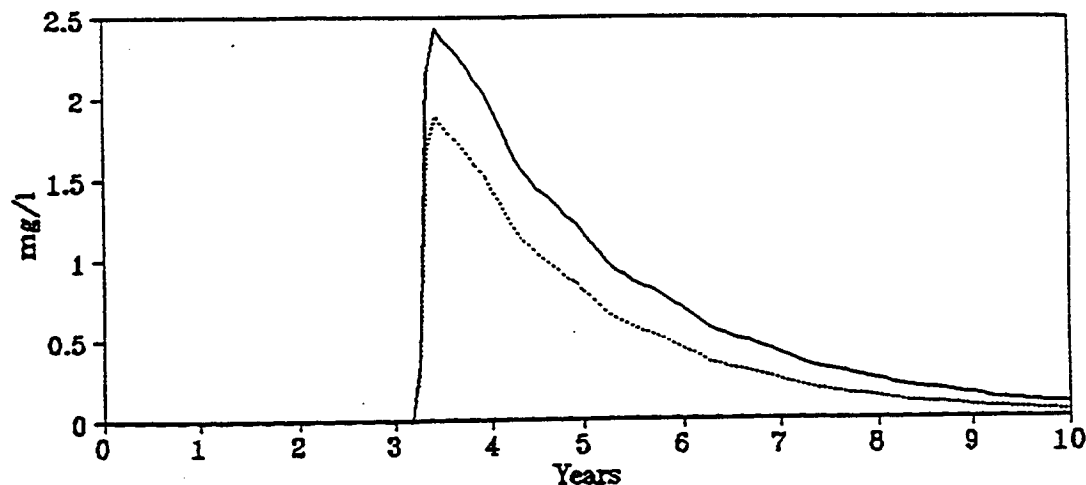
Soil pH	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
5.5	2.4	1.0	93 %
6.5	2.4	-	93 %
7.5	2.4	1.0	93 %

C:\1sesoil\benzene\ssout024, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout025

Figure B-21

## LAYER 4: BENZENE CONCENTRATIONS (SAND)

Biodegradation Rate



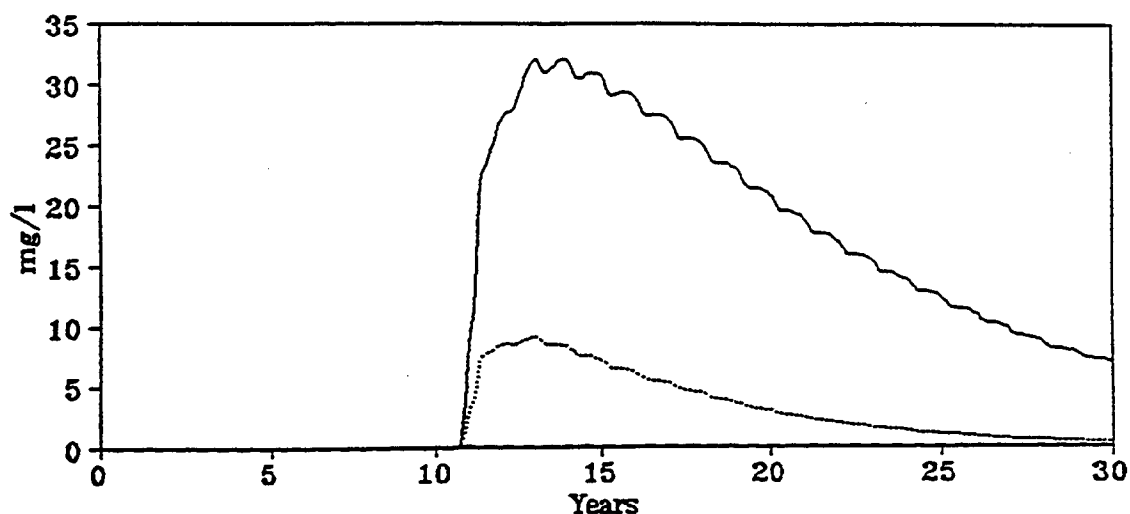
— 0.0 — 9.49 E-4 --- 6.93 E-2

Biodegradation Rate (1/day)	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0	2.4	-	93 %
9.49 E-4	1.9	0.79	84 %
6.93 E-2	1.0 E-9	4.2 E-10	8.1 %

C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout036, C:\1sesoil\benzene\ssout037

Figure B-22

# LAYER 4 BENZENE CONCENTRATIONS (TILL) Biodegradation Rate



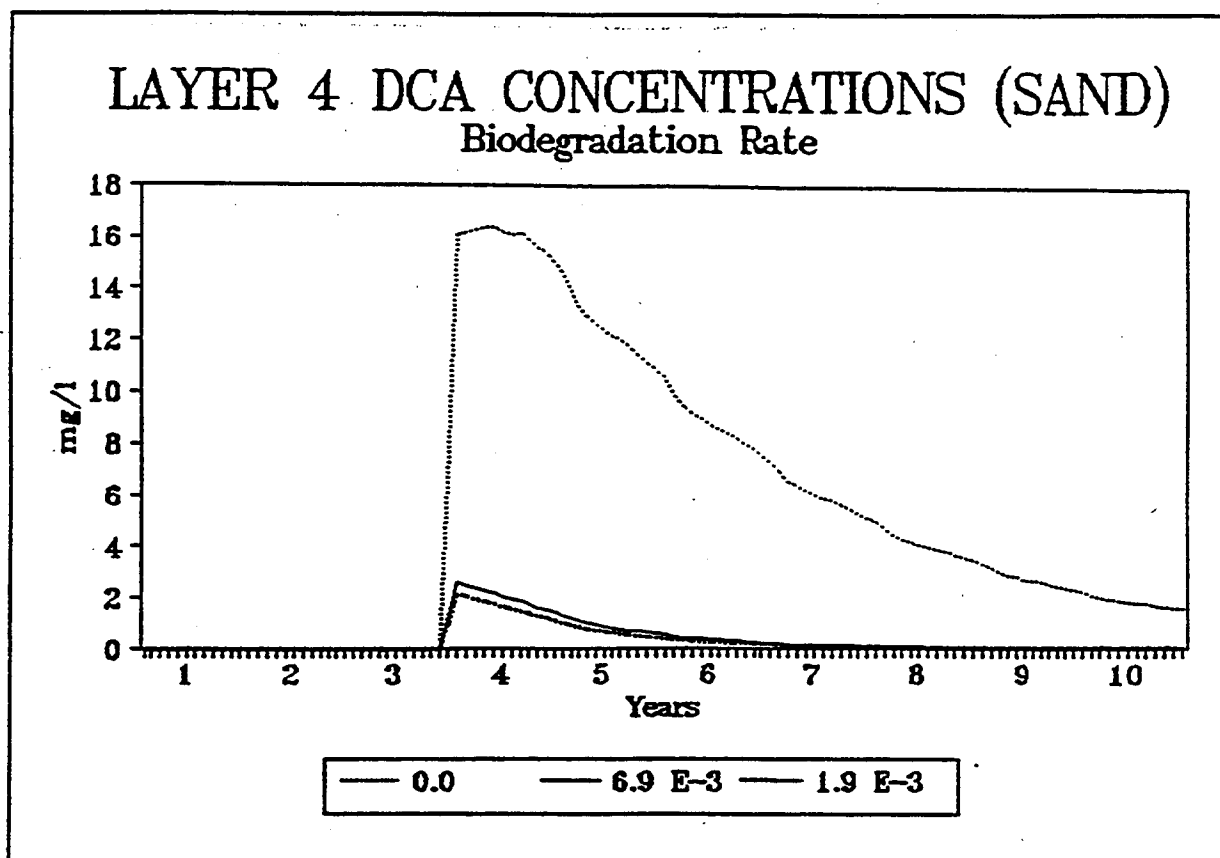
— 0.0 — 9.49 E-4 --- 6.93 E-2

Biodegradation Rate (1/day)	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0	32	-	4.1 %
9.49 E-4	9.0	0.28	2.3 %
6.93 E-2	1.0 E-9	3.1 E-10	0.0037 %

C:\2sesoil\benzene\ssout037, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout038

Figure B-23



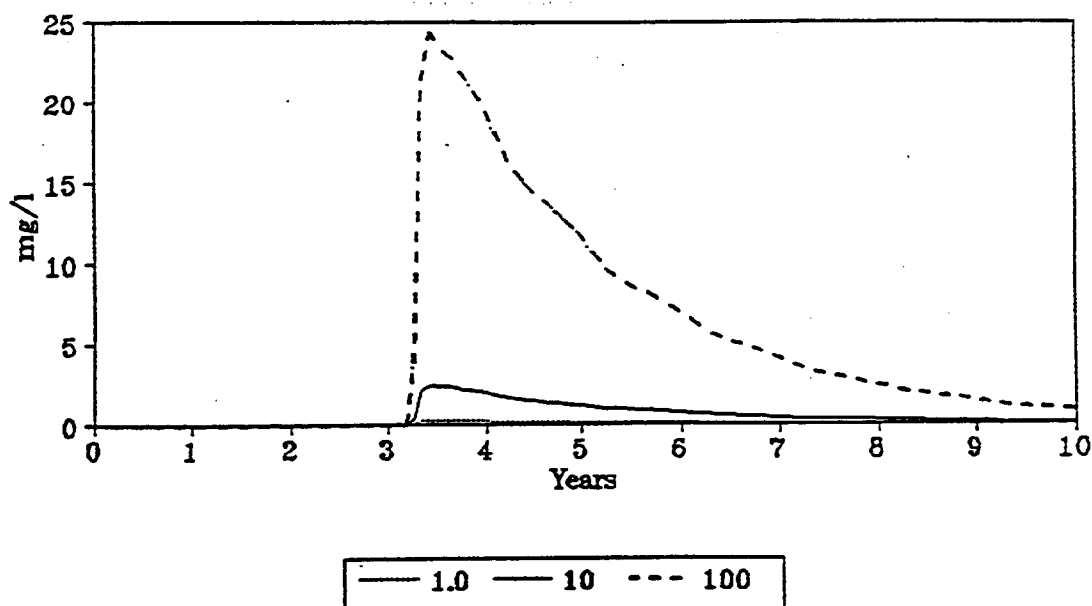


Biodegradation Rate 1/day	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
0	16	-	25 %
6.9 E-3	2.6	0.16	9.4 %
1.9 E-3	2.1	0.13	8.8 %

c:\2sesoil\dca\ssout027, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout026

Figure B-24

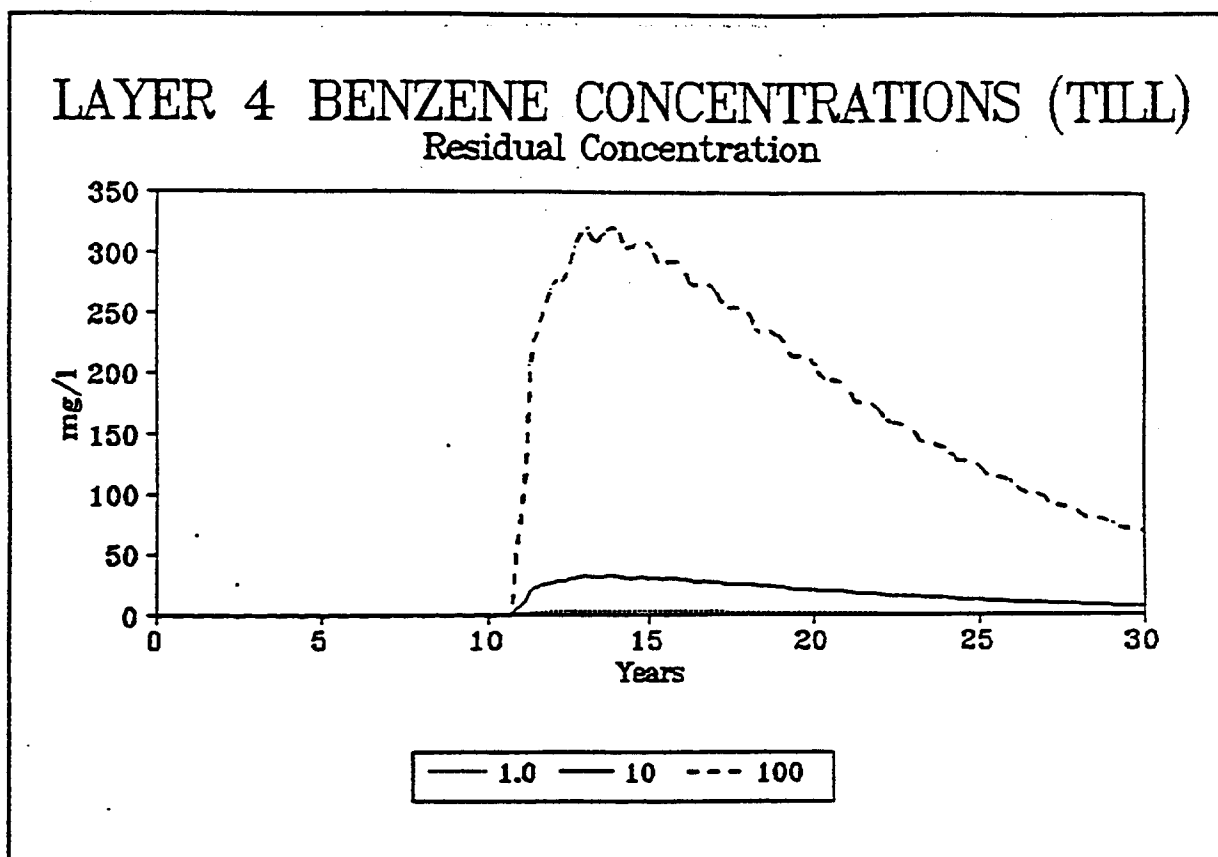
# **LAYER 4: BENZENE CONCENTRATIONS (SAND)** Residual Concentration



Residual Concentration ug/g	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1	0.24	0.1	93 %
10	2.4	-	93 %
100	24	10	93 %

C:\1sesoil\benzene\ssout039, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout040

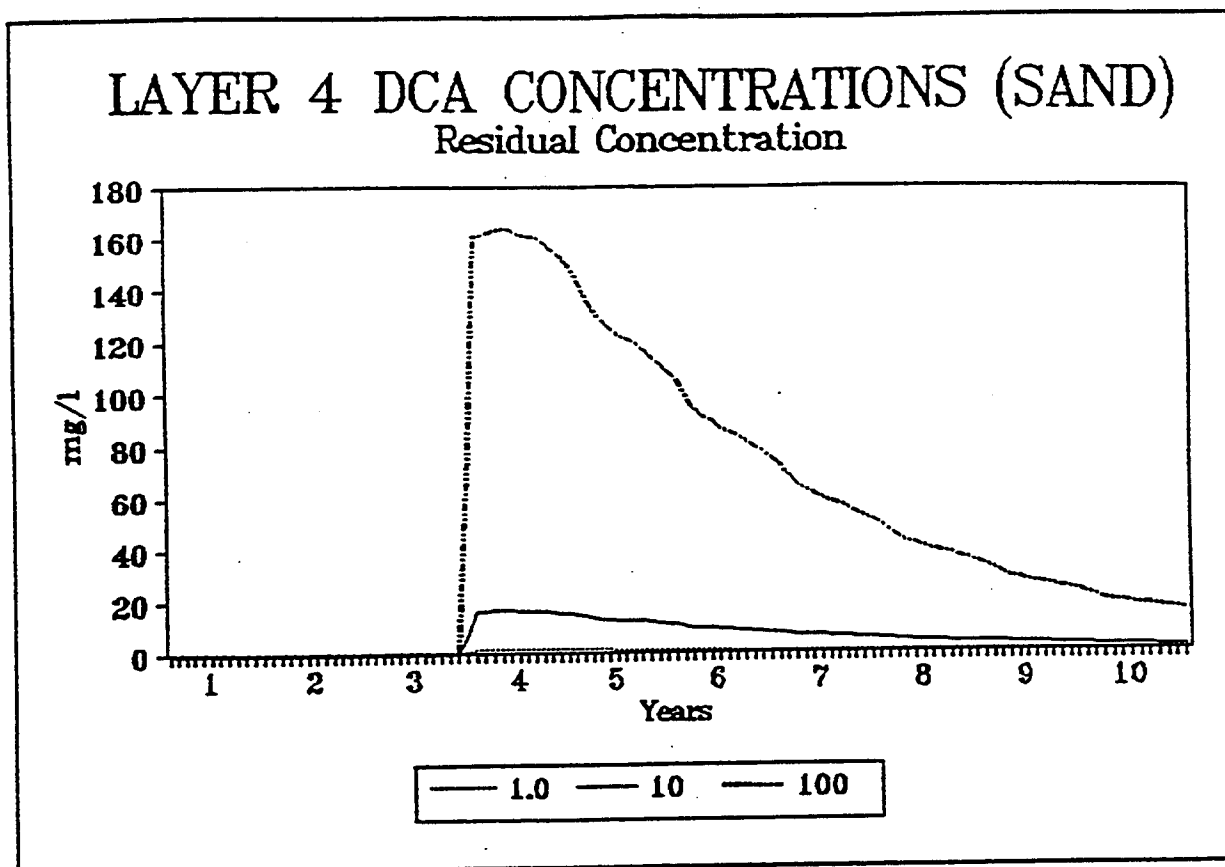
Figure B-25



Residual Concentration ppm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1.0	3.2	0.1	4.1 %
10	32	-	4.1 %
100	321	10	4.1 %

C:\2sesoil\benzene\ssout025, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout026

Figure B-26

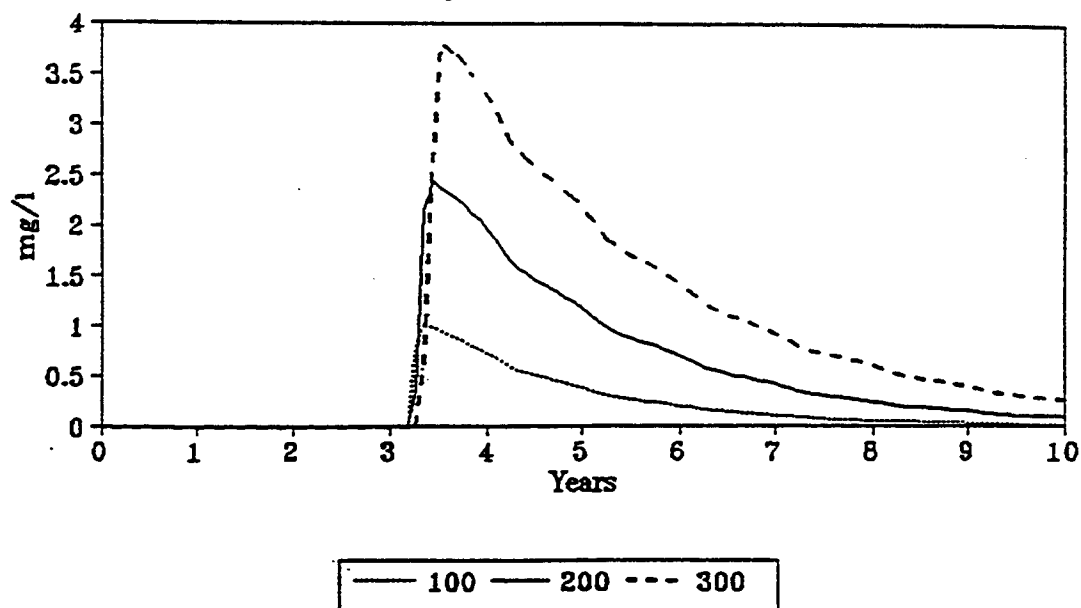


Residual Concentration ppm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
1.0	1.6	0.1	25 %
10.0	16	-	25 %
100.0	164	10	25 %

c:\2sesoil\dca\ssout030, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout031

Figure B-27

# LAYER 4: BENZENE CONCENTRATIONS (SAND) Layer 1 Thickness

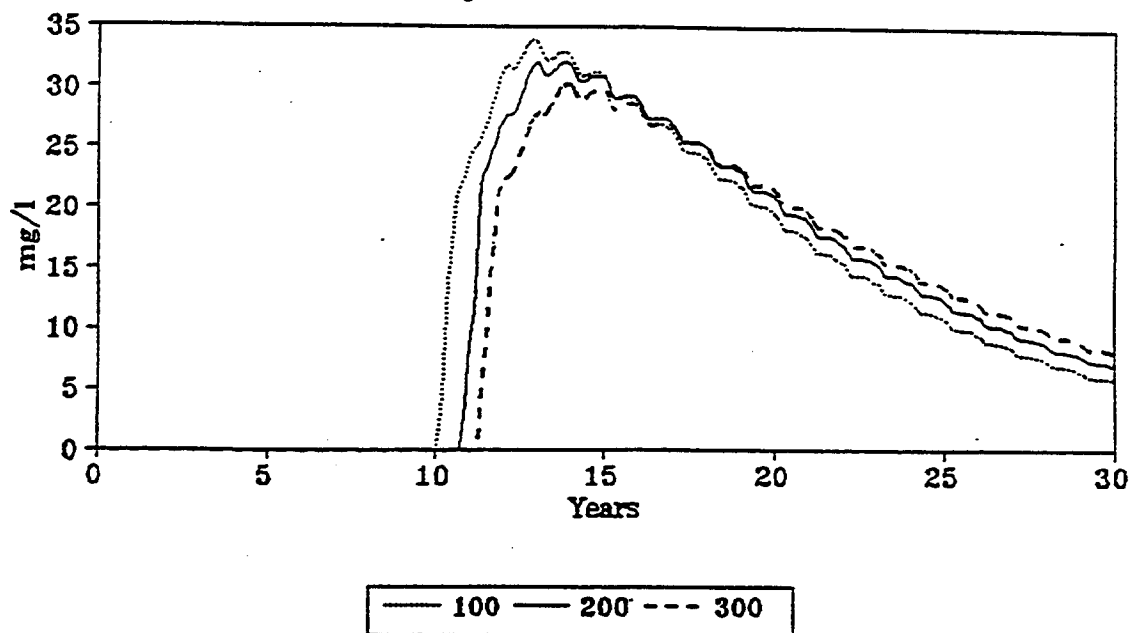


Layer 1 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	1.0	0.42	98 %
200	2.4	-	93 %
300	3.8	1.6	86 %

C:\1sesoil\benzene\ssout041, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout042

Figure B-28

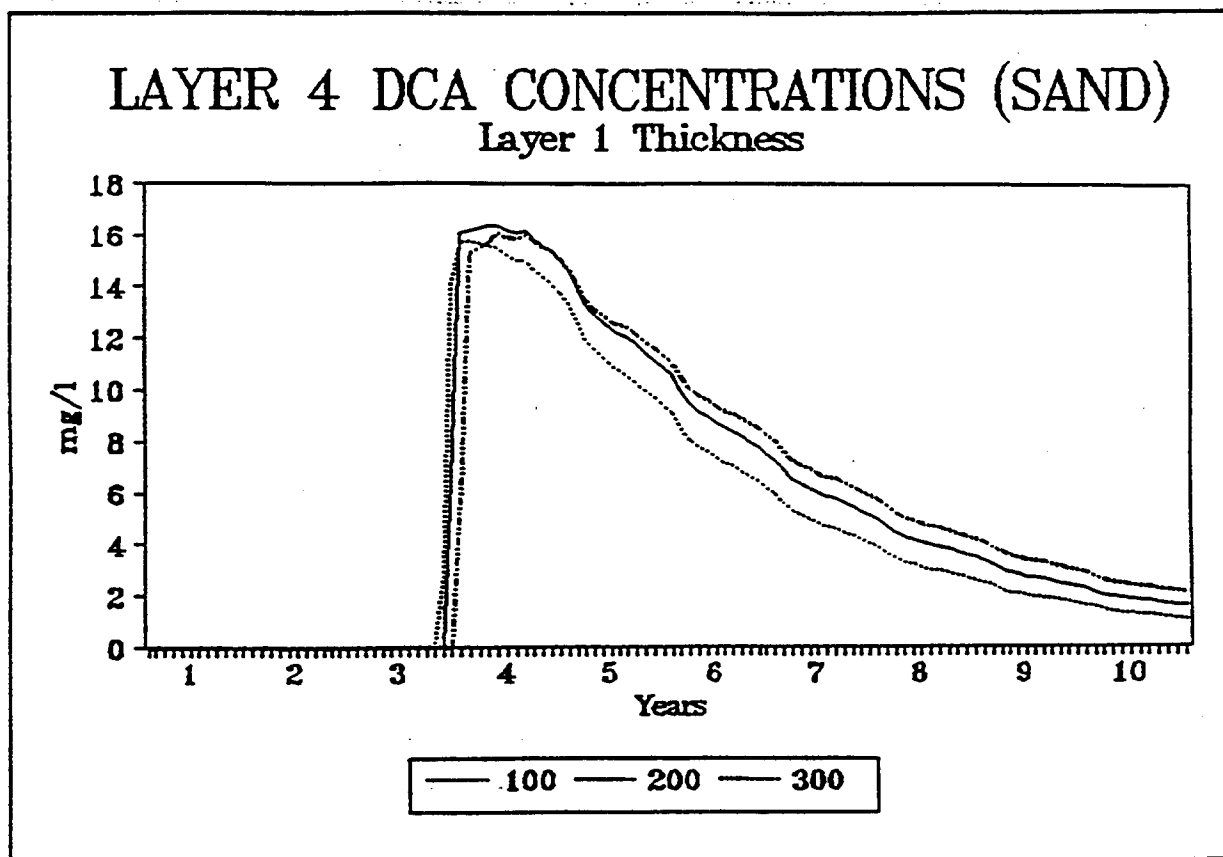
# LAYER 4 BENZENE CONCENTRATIONS (TILL) Layer 1 Thickness



Layer 1 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	34	1.1	6.2 %
200	32	-	4.1 %
300	30	0.94	3.3 %

C:\2sesoil\benzene\ssout027, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout028

Figure B-29



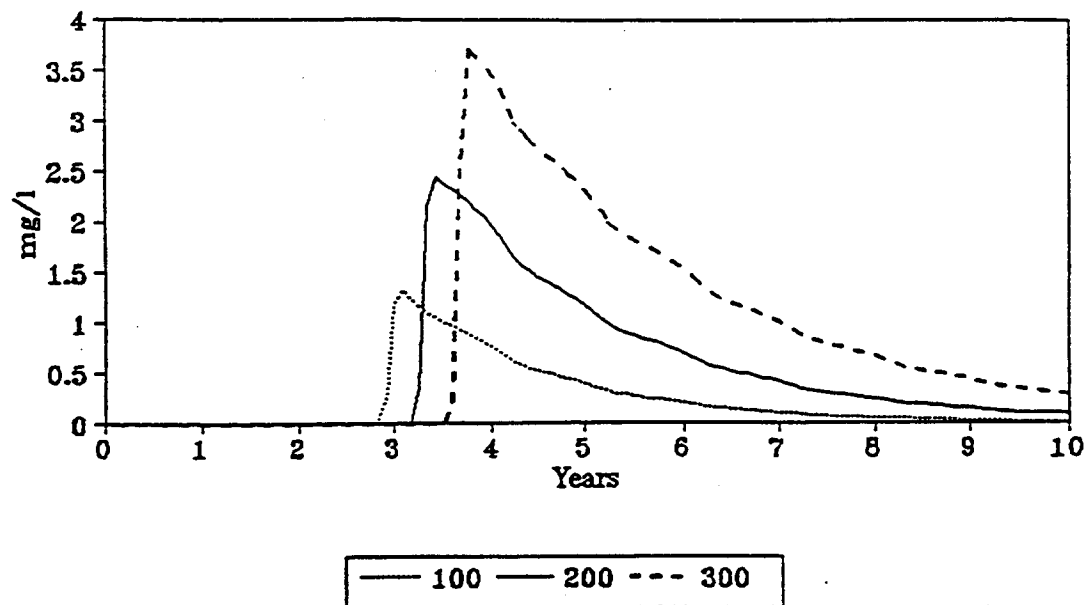
Layer 1 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	16	1.0	36 %
200	16	-	25 %
300	16	1.0	19 %

c:\2sesoil\dca\ssout032, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout033

Figure B-30

# LAYER 4: BENZENE CONCENTRATIONS (SAND)

Layer 2 Thickness

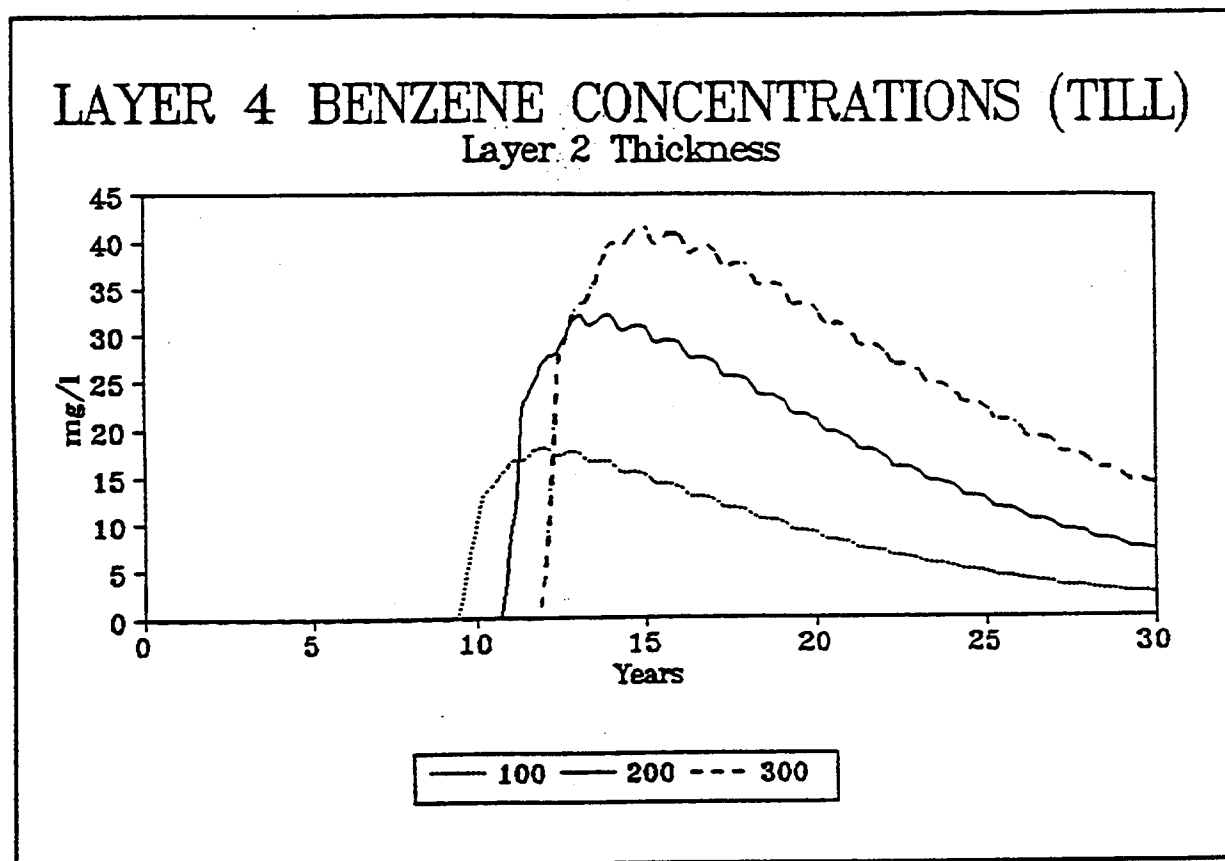


Layer 2 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	0.66	0.28	97 %
200	2.4	-	93 %
300	5.6	2.3	86 %

C:\1sesoil\benzene\ssout047, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout048

Figure B-31

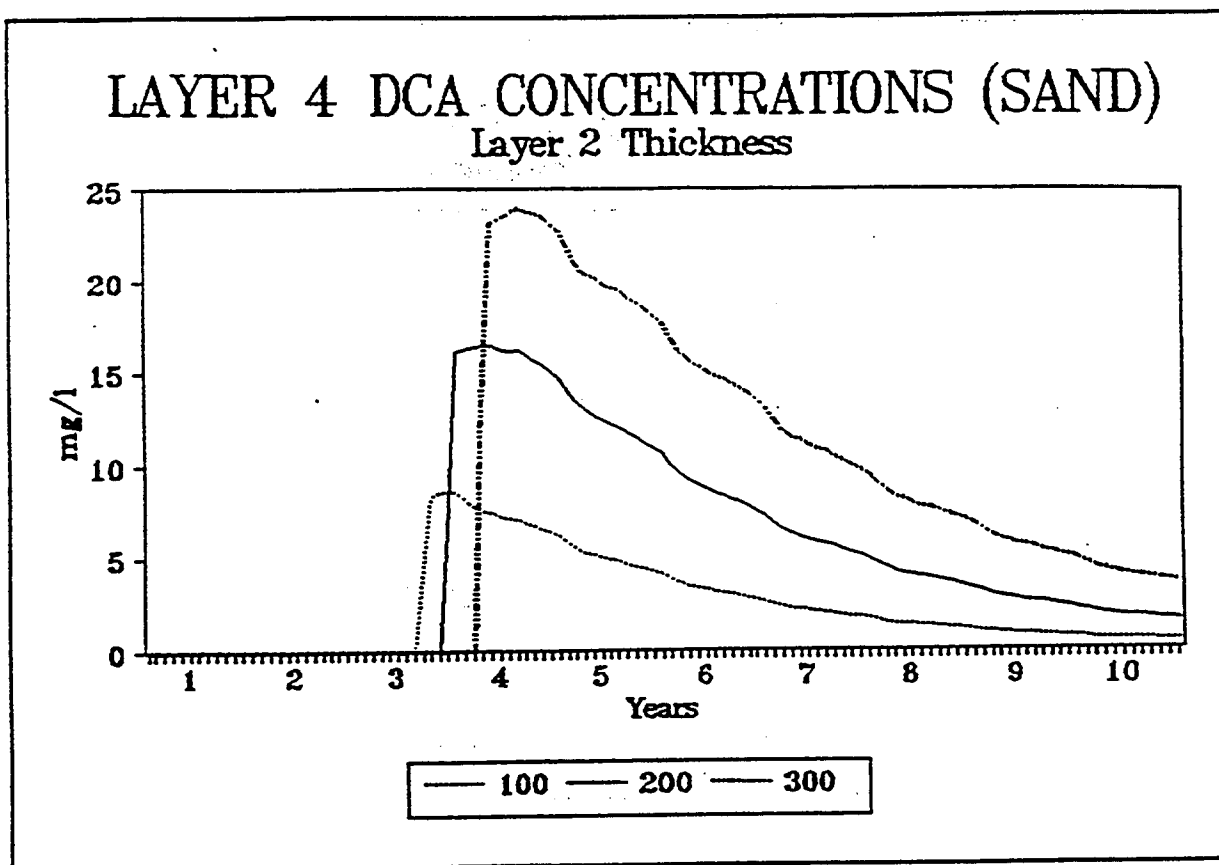




Layer 2 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	18	0.56	7.1 %
200	32	-	4.1 %
300	42	1.3	2.8 %

C:\2sesoil\benzene\ssout029, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout030

Figure B-32

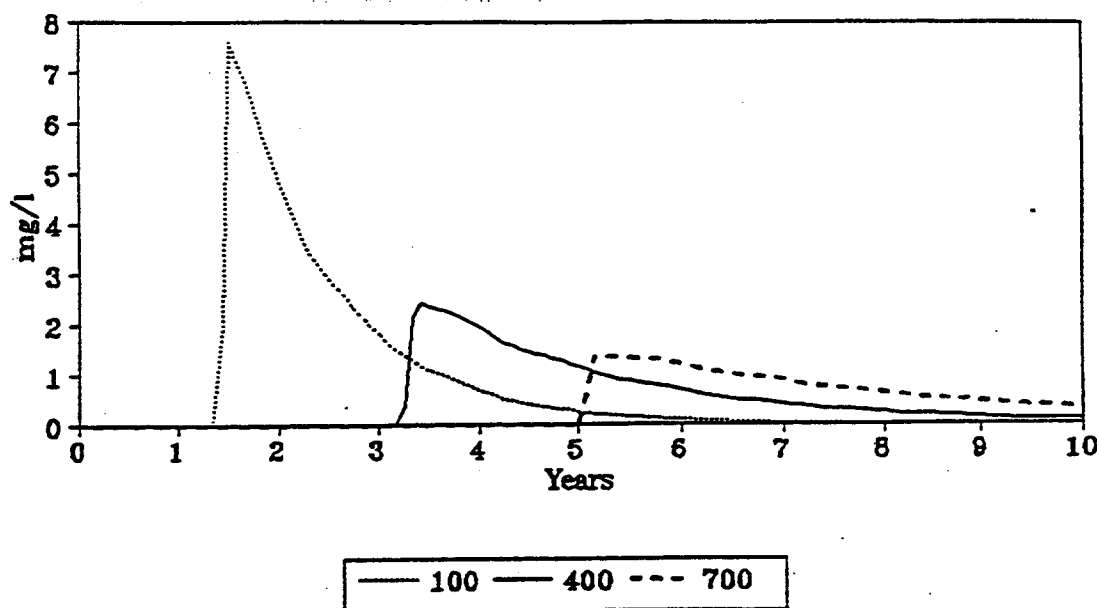


Layer 2 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	8.6	0.54	37 %
200	16	-	25 %
300	24	1.5	18 %

c:\2sesoil\dca\ssout034, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout035

Figure B-33

# LAYER 4: BENZENE CONCENTRATIONS (SAND) Layer 3 Thickness

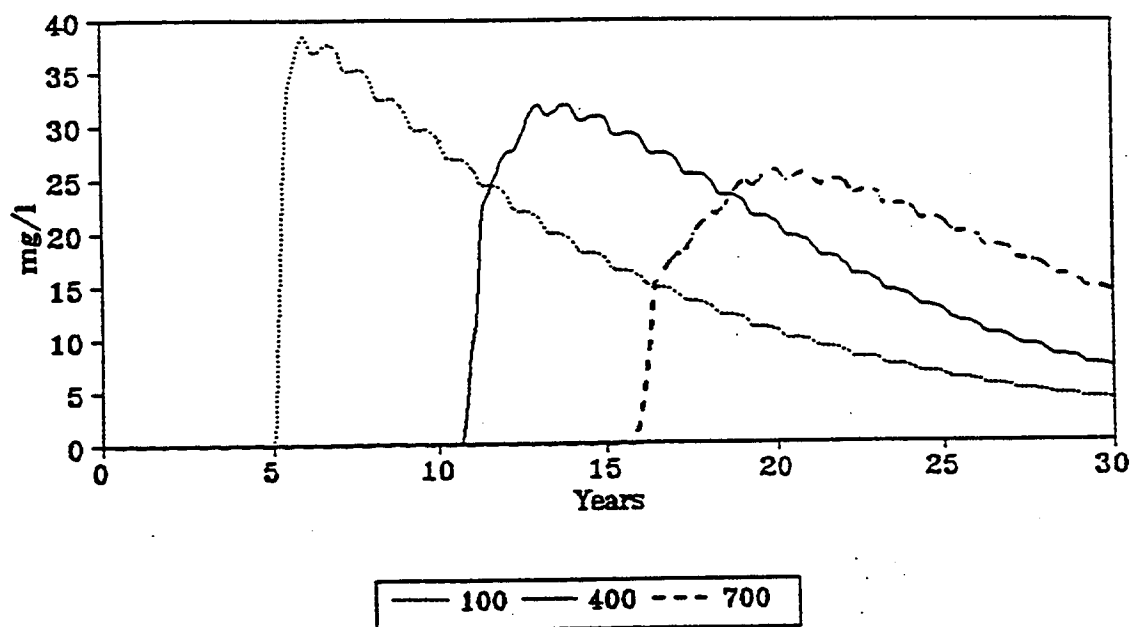


Layer 3 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	7.6	3.2	89 %
400	2.4	-	93 %
700	1.4	0.58	92 %

C:\1sesoil\benzene\ssout045, C:\1sesoil\benzene\ssout005, C:\1sesoil\benzene\ssout046

Figure B-34

# LAYER 4 BENZENE CONCENTRATIONS (TILL) Layer 3 Thickness

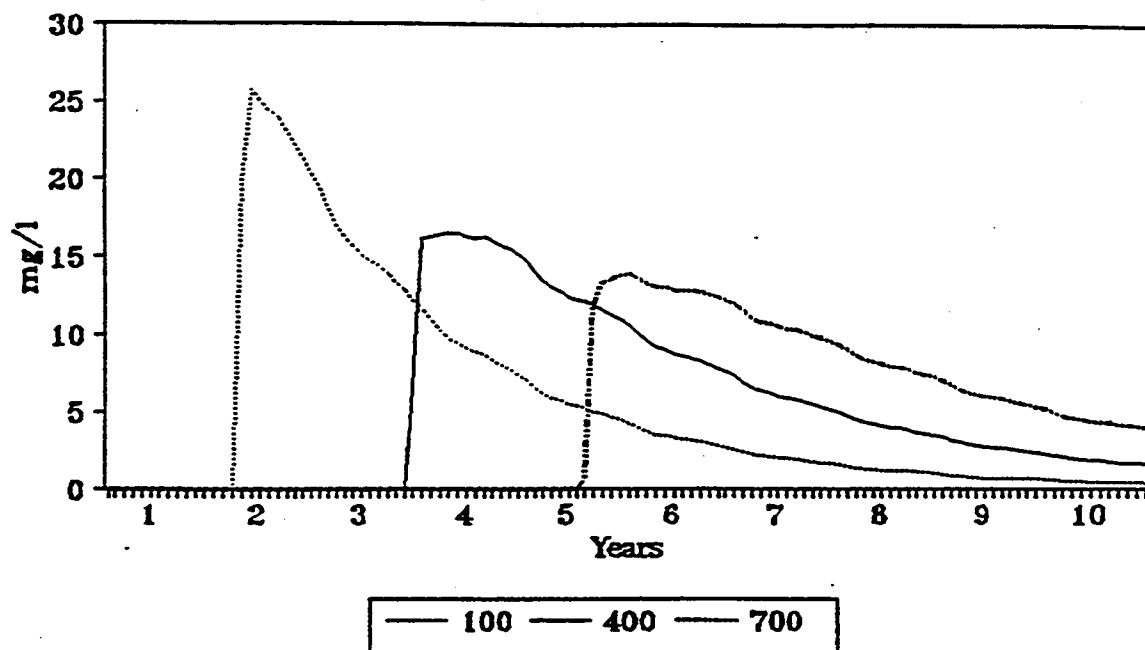


Layer 3 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	39	1.2	7.0 %
400	32	-	4.1 %
700	26	0.81	3.4 %

C:\2sesoil\benzene\ssout031, C:\2sesoil\benzene\ssout012, C:\2sesoil\benzene\ssout032

Figure B-35

# LAYER 4 DCA CONCENTRATIONS (SAND) Layer 3 Thickness



Layer 3 Thickness cm	Maximum Concentration		Percent Volatilized
	mg/l	Ratio	
100	26	1.6	27 %
400	16	-	25 %
700	14	0.88	23 %

c:\2sesoil\dca\ssout036, c:\2sesoil\dca\ssout015, c:\2sesoil\dca\ssout037

Figure B-36

## **APPENDIX C**

### **DESCRIPTION AND JUSTIFICATION OF SESOIL DEFAULT, TIER 1 PARAMETER VALUES**

## DESCRIPTION AND JUSTIFICATION OF SESOIL DEFAULT, TIER 1 PARAMETER VALUES

### Input Climate Data

Climate data incorporated into the standard and high rainfall models are presented in Table 1. Rainfall, evapotranspiration, and surface runoff are the primary elements of the climate data (other types of precipitation are insignificant in Hawai'i). The spatial and temporal variation of each of these parameters can be extremely high in Hawai'i. Mauka (mountain) areas on the windward sides of the islands typically receive annual rainfalls of 400 to 800cm/year (*Atlas of Hawai'i*, 1983). In sharp contrast, leeward, coastal areas located only a few kilometers away receive annual rainfalls of only 100cm or much less. Most developed areas of the islands, however, extend from the coast inland and are not subject to the intense mauka rains.

Using the annual rainfall maps provided in the *Atlas of Hawai'i* as a guide, an annual rainfall of 200cm is incorporated into the generic models as a conservative amount that includes almost all major developed areas on the islands. An exception is the northeast, windward side of the island of Hawai'i, where rainfall can average up to 400cm/year in developed areas (e.g., the Hilo area).

Climate data for numerous stations in Hawai'i are provided with the SESOIL application. Data for the Ahuimanu Loop climate station (island of O'ahu) most closely match the desired annual rainfall of 200cm/year (Table 1a). The actual annual precipitation reported for the Ahuimanu Loop station is 223.45cm. For use in the model simulations, monthly rainfalls totals were multiplied by 0.9 to match the desired total annual rainfall of 200cm. Climate data for the Honomu Mauka climate station (island of Hawai'i) are used to model high rainfall areas (Table 1b). Annual rainfall was adjusted from 438cm/year to 400cm/year for use in the models.

The amount of rainfall that infiltrates the subsurface and eventually recharges groundwater is equal to total rainfall minus evapotranspiration and surface runoff. Data regarding evapotranspiration and surface runoff are not, unfortunately, provided for either the Ahuimanu Loop or Honomu Mauka climate stations (or for any of the Hawai'i stations). Compounding the problem, because the vadose-zone soil and bedrock at the model impacted sites are conservatively assumed to be very permeable (described below), SESOIL calculates that there will be no surface runoff at the sites and in turn significantly over predicts groundwater recharge.

In the absence of data specific to the Ahuimanu Loop and Honomu Mauka climate stations, evapotranspiration, surface runoff, and groundwater recharge data are taken from information published in the *Atlas of Hawai'i* (1983). Groundwater recharge (as a percentage of rainfall, averaged over each island) is reported to range from a low of 5% on the island of Niihau to a high of 36% on the island of O'ahu. High recharge leads to a more rapid flushing of contaminants from the vadose zone and subsequently a greater impact on groundwater. For this reason, evapotranspiration, surface runoff,

and groundwater recharge data for the island of O'ahu (40%, 24%, and 36%, respectively) are chosen for incorporation into the model impacted sites.

Input evapotranspiration data are calculated by multiplying the monthly rainfall data by 0.4 (40%) and converting the result to cm/day as required in the SESOIL module. Surface runoff is then accounted for by reducing the input monthly rainfall data by 24%. After subtracting evapotranspiration, the resulting annual groundwater recharge equals approximately 36% of the adjusted annual rainfall, as desired:

$$\begin{aligned}\text{recharge} &= \text{rainfall} - (\text{evapotranspiration} + \text{surface runoff}) \\ &= 200\text{cm} - ((200 \times 0.4) + (200 \times 0.24)) \\ &= 72\text{cm}\end{aligned}$$

or 144cm for the high-rainfall scenario. Temperature data are also not included in the Ahuimanu Loop or Honomu climate station data. Data from the Kaneohe Mauka station (island of O'ahu, Owenby and Ezell, 1992), which receives approximately 200cm of annual rainfall, are included for use in the models.

Groundwater recharge, in centimeters, is reported as "Groundwater Runoff" under the "Hydrologic Cycle Components" section of the SESOIL output file. In order to avoid confusion with pollutant "Groundwater Runoff" also reported in the output file, the hydrologic component of the groundwater runoff is referred to as "groundwater recharge," "recharge water," or "leachate" throughout the remainder of the report.

## **Input Soil Properties and Soil Column Properties**

### **Geologic Model**

The default impacted-site geologic model has 4 layers (Figure 1): 1) an upper layer of impacted soil, 2) an underlying layer of non-impacted soil, 3) a lower layer of non-impacted, basaltic bedrock that extends from the base of the soil to just above the top of groundwater, and 4) a thin layer of non-impacted, basaltic bedrock at the base of the column that is used to monitor what is passing out of the vadose zone and into the groundwater.

The thickness of the upper, impacted soil layer is fixed at two meters (see Figure 1). Though some sites occasionally report impacted soil thicknesses of greater than two meters, DOH feels that this is a conservative estimate for the majority of impacted sites encountered in Hawai'i. The thickness of the lower, non-impacted interval of soil is conservatively set at one meter.

The sensitivity of depth to groundwater on leachate fate and transport is modeled by varying the thickness of the basalt interval underlying the soil (see Figure 1). For example, in the Tier 1A criteria, the thickness of this basalt interval is 4 meters. When added to the non-impacted soil interval this gives a depth to groundwater of 5 meters, as measured from the base of the impacted layer. Successive model simulations used basalt thicknesses of 9 meters, 19 meters, etc. As noted later, the difference in the



predicted groundwater impact, and subsequently in the soil action levels generated, can be quite dramatic.

The bottom layer is held to a constant thickness of 1cm (minimum thickness recommended for use in the simulations). Incorporating a thin layer at the base of the geologic column increases the accuracy of the pollutant "Groundwater Runoff" output.

The area of the generic models is set to 1,000cm<sup>2</sup>. Note that the area of the model site is used simply to determine the input mass and subsequent distribution of the contaminant load and has no direct influence on the concentration of the contaminant in leachate generated from the site.

### **Permeability and Organic Carbon Content**

Contaminant leachate has the greatest impact on groundwater when it is allowed to pass through the vadose as rapidly as possible without undergoing significant degradation (e.g. through volatilization and biodegradation). In SESOIL, the driving force behind the ability of the vadose-zone media to transport dissolved contaminants is the permeability of the media and the fraction of organic carbon (foc) in the media. High permeability permits rapid migration of infiltrating surface water to groundwater. Low foc minimizes transport retardation of a contaminant as it is carried through the vadose zone.

Permeability and foc data chosen for the generic, model sites are based on information published by the U.S. Department of Agriculture (Foote et al., 1972; USDOA, 1976; USDOA, 1992) and the University of Hawai'i - Manoa Water Resources Research Center (Miller et al., 1988; Mink and Lau, 1990), and also on discussions with local experts of Hawaii's soils and hydrogeology (Table 2). Because the majority of impacted sites are on O'ahu, soil data from this island are used in the models. The data presented in Table 2 are representative of soil and bedrock types on the other islands of Hawai'i.

Many of the local experts consulted with commented that USDOA-reported permeabilities for silty clay saprolites of the islands are too low for many areas. Miller et al. (1988) report a range of saturated hydraulic conductivities in subsoil and saprolite in central O'ahu of 10<sup>-3</sup> to 10<sup>-8</sup>m/s (permeability 10<sup>-6</sup> to 10<sup>-11</sup>cm<sup>2</sup>) with the majority of the data falling below 10<sup>-4</sup>m/s (permeability 10<sup>-7</sup>cm<sup>2</sup>). As a conservative approach, a permeability of 1E-7cm<sup>2</sup> is used for both soil intervals in the model, roughly approximating a very permeable soil/saprolite or a sandy coastal plain soil/sediment.

Reported foc values for the most common soil types on O'ahu range from 0% to 1% for depths greater than or equal to 60cm below the surface. As a conservative approach, the foc in the soils of the generic, model site is set at 0.1%.

The effective porosity of the soil was set at 30% and the density set to 1.5 (an average of saprolite and sand). The Freundlich equation exponent is set at one in the

model. This gives rise to a linear relationship between input soil concentration and output groundwater impact as long as pure-phase contaminant is not present in the soil.

The SESOIL application initially applies data input under "Soil Properties" to all layers of the vadose-zone model. In the "Soil Column Properties" data input module, however, SESOIL allows modification of layer-specific permeabilities and foc. The permeability of the basaltic bedrock in Hawai'i varies tremendously, from lows of less than  $1\text{E-}8\text{cm}^2$  to highs of greater than  $4\text{E-}6\text{cm}^2$  (see Table 2). After discussions with local experts on the hydrogeology of Hawai'i, a permeability of  $1\text{E-}6\text{cm}^2$  ( $k = 100\text{m/day}$ ) was chosen for the models as a conservative but generally representative value. The foc of the model basalt adjusted to 0.0001%, reflecting an assumption that there is little organic carbon (or even clay) present in basaltic bedrock for a contaminant to sorb to as it is carried downwards.

### **Physio-Chemical Constants**

Physio-chemical constants used in the SESOIL models are presented in Table 3. Published physio-chemical properties for some of the contaminants modeled can vary widely from source to source. For consistency with EPA models used to generate direct-exposure soil screening guidelines, DOH has chosen to use physio-chemical constants provided in the EPA Region IX document "Preliminary Remediation Goals (PRGs)" (USEPA, 1995). As noted in Table 3, where data for a particular contaminant are not provided in the PRG reports other references are used. In particular, DOH refers to "Groundwater Chemicals Desk Reference" by Montgomery and Welkom (1991) and data provided in the American Petroleum Institute's "Transport and Fate of Non-BTEX Petroleum Chemicals in Soils and Groundwater (Neff et al., 1994)."

DOH recognizes the important role that biodegradation plays in the natural attenuation of many organic contaminants (especially given Hawaii's year-round warm climate) and incorporates a conservative approach to its use in the SESOIL models, despite the uncertainty of site-specific or even laboratory-determined degradation rates. The "Handbook of Environmental Degradation Rates" by Howard et al (1991) is the most comprehensive compilation of biodegradation data available and, in order to maintain consistency in the choice of biodegradation rates, is used as the main reference.

Table 4 provides a summary of aerobic and anaerobic biodegradation data for the contaminants discussed in this report. The fate-and-transport scenario adopted for use in the models assumes that a contaminant biodegrades in a moderately unfavorable environment and that liquid-phase (dissolved) degradation dominates over solid-phase (sorbed) degradation. Following this objective, the liquid-phase half-life for a VOC is chosen as the minimum (shortest) reported anaerobic half-life presented for the contaminant or the longest aerobic half-life, whichever is greater (Table 4). The liquid-phase half-life for an HVOC is chosen as the maximum (longest) reported aerobic half-life or the shortest anaerobic half-life, whichever is greater. For SVOCs, either the maximum aerobic or minimum anaerobic half-life is chosen, whichever is more

conservative (longest). As noted in Table 4, most non-halogenated, volatile organic compounds (VOCs) are assumed to degrade in a moderately anaerobic environment. Most halogenated, volatile organic compounds (HVOCs), in contrast, are assumed to degrade in a moderately aerobic environment. Semi-volatile organic compounds (SVOCs) as a group do not show a distinct preference for aerobic versus anaerobic biodegradation.

Biodegradation rates are calculated as:

$$\text{Biodegradation Rate} = \text{LN2/half-life.}$$

Solid-phase biodegradation rates are assumed to be equivalent to half the liquid-phase degradation rate chosen for each contaminant. Note that contaminant complexation and hydrolysis are not included in the models.

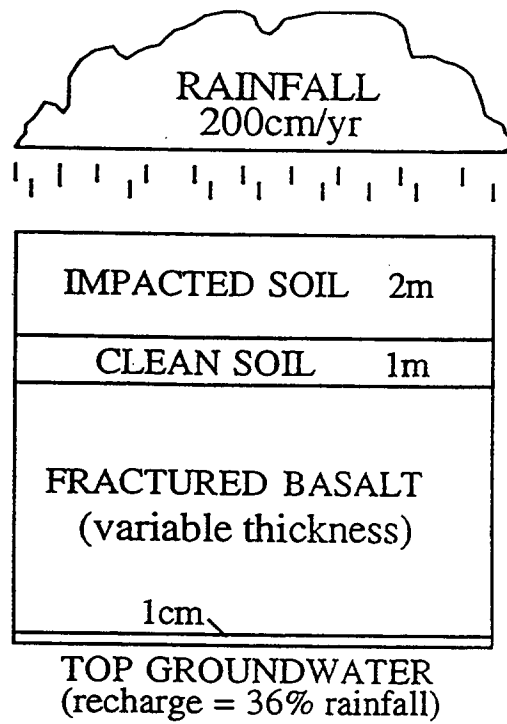


Figure 1. Geologic profile of generic model.

TABLE 1A. Monthly climate data used in Tier 1 SESOIL standard-rainfall models.  
(Modified Ahuimanu Loop climate station data).

Month	<sup>1</sup> Air Temperature (°C)	<sup>2</sup> Evapotranspiration (cm/day)	<sup>3</sup> Precipitation (cm/month)	Duration (days)	Number of Storms	Month Length (days)
Oct.	25	0.21	12.02	0.31	12.2	30.4
Nov.	24	0.24	14.06	0.36	12.2	30.4
Dec.	23	0.28	15.90	0.43	11.1	30.4
Jan.	22	0.39	22.54	0.50	10.0	30.4
Feb.	22	0.22	12.88	0.35	10.1	30.4
Mar.	22	0.28	16.37	0.33	12.6	30.4
Apr.	23	0.27	15.32	0.36	13.6	30.4
May	24	0.18	10.68	0.27	13.0	30.4
June	25	0.14	7.87	0.26	11.5	30.4
July	25	0.14	8.10	0.29	12.5	30.4
Aug.	25	0.16	9.19	0.26	12.8	30.4
Sept.	25	0.14	7.92	0.23	11.8	30.4
<p>Annual Totals:    Precipitation: 200cm, Evapotranspiration: 80cm, Surface Runoff: 48cm (Groundwater Recharge = 72cm)</p> <p>1. Air temperature data from Kaneohe Mauka climate station (Owenby and Ezell, 1992). All other data modified from Ahuimanu Loop climate station.</p> <p>2. Evapotranspiration calculated as 40% of daily rainfall.</p> <p>3. Ahuimanu Loop monthly precipitation adjusted to produce 200cm annual rainfall versus actual 223cm/yr. Input precipitation reduced by 24% to account for surface runoff.</p>						

TABLE 1b. Monthly climate data used in Tier 1 SESOIL high-rainfall models. (Modified Honomu Mauka climate station data).

Month	<sup>1</sup> Air Temperature (°C)	<sup>2</sup> Evapotranspiration (cm/day)	<sup>3</sup> Precipitation (cm/month)	Duration (days)	Number of Storms	Month Length (days)
Oct.	25	0.38	22.09	0.49	15.2	30.4
Nov.	24	0.51	29.59	0.70	11.5	30.4
Dec.	23	0.45	25.67	0.59	11.5	30.4
Jan.	22	0.35	19.74	0.62	7.9	30.4
Feb.	22	0.38	22.27	0.51	9.7	30.4
Mar.	22	0.76	43.66	0.80	14.0	30.4
Apr.	23	0.68	39.43	0.69	16.2	30.4
May	24	0.32	18.33	0.47	15.7	30.4
June	25	0.27	15.65	0.53	13.4	30.4
July	25	0.41	23.86	0.59	16.9	30.4
Aug.	25	0.47	27.53	0.50	15.4	30.4
Sept.	25	0.26	15.40	0.47	13.8	30.4
<p>Annual Totals:   <sup>2</sup>Precipitation: 400cm, Evapotranspiration: 160cm, Surface Runoff: 96cm (Groundwater Recharge = 144cm)</p> <p>1. Air temperature data from Kaneohe Mauka climate station (Owenby and Ezell, 1992). All other data modified from Honomu Mauka climate station.</p> <p>2. Evapotranspiration calculated as 40% of daily rainfall.</p> <p>3. Honomu Mauka monthly precipitation adjusted to produce 400cm annual rainfall versus actual 438cm/yr. Input precipitation reduced by 24% to account for surface runoff.</p>						

TABLE 2. Physical properties of basalt and common soil types in Hawai'i.

Properties	Basalt	Saprolite (a)	Saprolite (b)	Sand
Range Hydraulic Conductivity (in/hr)	-	2 to 6	0.6 to 2.0	6 to 20
Range Hydraulic Conductivity (m/d)	up to 300+	1 to 4	0.1 to 0.4	4 to 12
Range Permeability (cm <sup>2</sup> )	1E-8 to 4E-6	1E-8 to 5E-8	5E-9 to 1E-8	5E-8 to 1E-7
Model Hydraulic Conductivity (m/d)	100	4	0.4	12
Model Permeability (cm <sup>2</sup> )	1E-06	5E-08	5E-09	1E-07
Organic Carbon at >50cm depth (%)	no data	0 to 1.0%	0 to 1.0%	0 to 0.1%
Bulk Density (g/cm <sup>3</sup> )	1.6	1.3	1.3	1.7

Saprolite (a): Silty clay - Waihiawa, Helemano, Waikane, Lolekaa soil series.

Saprolite (b): Silty clay - Ewa, Waialua soil series.

Sources of published data:

1. Soil Survey of the Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawai'i (Foote et al., 1972);
2. Soil Survey Laboratory Data and Descriptions for Some Soils of Hawai'i (USDOA, 1976);
3. Hydrogeologic Characteristics of Subsoil and Saprolite and Their Relation to Contaminant Transport, Central O'ahu, Hawai'i (Miller et al., 1988);
4. Aquifer Identification and Classification for O'ahu (Mink and Lau, 1990);
5. Hawai'i Field Office Technical Guide (Section II, Engineering Index Properties, USDOA, 1992).

TABLE 3. Physio-chemical constants used in Tier 1 SESOIL models.

<sup>1</sup> Constituent	Water Solubility (mg/l)	Diffusion Coefficient-air (cm <sup>2</sup> /s)	Henry's Constant (m <sup>3</sup> -atm/mole)	KOC (ml/g)	Molecular Weight
Benzene	1800	0.088	0.0055	65	78
Toluene	520	0.078	0.0066	260	92
Ethylbenzene		0.075	0.0079	220	110
Xylene (mixed)	200	0.087	0.0053	240	110
<sup>2</sup> Benzo(a)pyrene	0.0039	0.045	0.0000024	881000	252
Acenaphthene	4	0.064	0.0012	4600	150
<sup>2</sup> Fluoranthene	0.26	0.051	0.0000087	41700	202
Naphthalene	31	0.069	0.0013	1300	130
PCE	150	0.072	0.023	660	170
1,1 DCE	400	0.079	0.15	65	97
Vinyl Chloride	1100	0.110	0.70	57	63
TCE	1000	0.081	0.0089	130	130
1,1,1 TCA	950	0.080	0.0028	150	130

1. Source of data USEPA (1995) unless otherwise noted.

2. Data after Montgomery and Welkom (1991) and Neff et al. (1994).



TABLE 4. Biodegradation constants used in Tier 1 SESOIL models.

Constituent	Range Aerobic Half- life (days)	Range Anaerobic Half- life (days)	Model Liquid- Phase Half- life (days)	Model Liquid- Phase Biodegradation Rate (1/days)	Model Solid- Phase Biodegradation Rate (1/days)
Benzene	5 to 16	112 to 730	112	0.0062	0.0031
Toluene	4 to 22	56 to 210	56	0.0124	0.0062
Ethylbenzene	3 to 10	176 to 228	176	0.0039	0.0020
Xylene (mixed)	7 to 28	180 to 365	180	0.0039	0.0019
Benzo(a)pyrene	56 to 529	228 to 2117	529	0.0013	0.0007
Acenaphthene	12.3 to 102	49.2 to 408	102	0.0068	0.0034
Fluoranthene	140 to 440	558 to 1774	558	0.0012	0.0006
Naphthalene	0.5 to 20	25 to 258	25	0.0277	0.0139
PCE	180 to 365	98 to 1643	365	0.0019	0.0009
1,1 DCE	28 to 180	81 to 173	180	0.0039	0.0019
Vinyl Chloride	28 to 180	112 to 730	180	0.0039	0.0019
TCE	180 to 365	98 to 1642	365	0.0019	0.0009
1,1,1 TCA	140 to 273	560 to 1092	560	0.0012	0.0006

Half-life data after Howard et al. (1991).

## **APPENDIX D**

### **RUNNING, CALIBRATING, AND INTERPRETING SESOIL MODELS**

## **RUNNING, CALIBRATING, AND INTERPRETING SESOIL MODELS**

### **INTRODUCTION**

Technical aspects of the use of SESOIL to generate soil action levels are discussed. Proper use of the SESOIL application for Tier 1 and Tier 2 purposes includes: 1) extraction of leachate contaminant concentrations from the output file data, 2) calibration of the model to yield target groundwater-protection objectives, and 3) extraction of soil action levels from the calibrated output file data. The procedures outlined in the main text of this document and clarified below must be followed for Tier 2 use of the application.

### **APPLICATION AND POLLUTANT LOADING INPUT DATA**

Memory limitations of the IBM 486DX computer used to run the SESOIL application restrict model simulation times to 25 years or less, though this is sufficient to evaluate the migration of most contaminants. Accordingly, 25 years of application data are input into the model. A one-time pollutant load is input into layer 1 during the first month of the simulation. A pollutant load of "zero" is input for each successive month of the remaining 25 year simulation period. The model release mode is set to "instantaneous spill," again to reflect existing residual contamination. (Note that setting the release mode to "instantaneous spill" (one-time loading) versus "continuous spill" (loading spread out over the month) makes no significant difference in the calculated groundwater impact for the model scenarios used.)

Both biodegradation and volatilization are initiated at the beginning of the model run (mandatory for biodegradation and pre-set this way for volatilization). The volatilization fraction parameter of the "Pollutant Loading" SESOIL module allows the user to adjust how effectively a volatile contaminant escapes to the atmosphere. Studies by the State of Oregon Environmental Cleanup Division (Anderson, 1992) indicated that the SESOIL application may over predict contaminant loss due to volatilization when 100% of the potentially volatilized fraction is allowed to escape. They chose to impose a limit of 20% on the maximum potential volatilization of a contaminant. As indicated in table 1-3 and 2-2 of the main document, DOH has chosen to follow the same procedure.

### **EXTRACTION OF LEACHATE CONTAMINANT CONCENTRATIONS FROM OUTPUT FILES**

The SESOIL application is used to correlate the concentration of a contaminant in soil with the concentration of the contaminant in leachate derived from that soil at the point the leachate passes into groundwater. Unfortunately, the version of SESOIL used in the modeling effort (SESOIL 1.07) does not directly compute the concentration of a contaminant in leachate at the point that the leachate passes into groundwater. Instead, the application calculates the mass, in micrograms (ug), of dissolved-phase contaminant that enters the groundwater each month via the recharge water and

reports this as "Groundwater Runoff" in the "Pollutant Mass Distribution in Column" section of the output file.

The month-averaged concentration of the contaminant in the leachate (in ug/ml) at the point that the leachate passed into the groundwater can, however, be extracted from the SESOIL output data by dividing the months contaminant mass "runoff" by the volume of leachate generated during that month:

$$\text{Contaminant Concentration} = (\text{Runoff Mass/Leachate volume})$$

The volume of leachate ( $V_l$ , in  $\text{cm}^3$  or more appropriately in milliliters) produced during a particular month is easily determined by relating the input model area ( $A$ , in  $\text{cm}^2$ ) to that months "groundwater runoff ( $r$ , in  $\text{cm}$ )" as reported under the hydrological cycle of the output file:

$$V_l = A \times r.$$

For example, given the general model setup, a reported monthly recharge of 5cm over a  $1,000\text{cm}^2$  area would equal  $5,000\text{cm}^3$  or 5,000ml of water entering the aquifer from the model site during that month. If the contaminant mass runoff for that month were 5ug then the concentration of the contaminant in the leachate at the point the leachate passed into the groundwater would be 0.001ug/ml. This same technique is used to "calibrate" a model simulation to produce a target leachate concentration as described below.

## **CALIBRATION OF SESOIL MODEL SIMULATIONS**

SESOIL is a "forward modeling" fate-and-transport application and is specifically designed to predict groundwater impact based on input contaminant concentrations in soil.

"Backward modeling" applications, where the application determines soil action levels from input target groundwater-protection objectives, are preferable for the purpose of establishing Tier 1 or Tier 2 soil action levels.

SESOIL can, however, be used for backward modeling by manipulating, or calibrating, the application to yield target a leachate concentration and then carefully evaluating the output file to determine what contaminant soil concentration lead to the calibrated impact. This is a relatively simple process, as follows:

- 1) Input a random contaminant concentration into the pollutant loading module and run the simulation. The input concentration should be low enough (generally 10ug/g is sufficient) ensure that pure-phase product is not present in the model impacted layer during the first month of the simulation.
- 2) Determine the year and month of the maximum, month-averaged contaminant concentration (ug/month) in the recharge water ("Groundwater Runoff" of pollutant mass reported in the monthly "Pollutant Mass Distribution" output

divided the corresponding volume of recharge water for that month). Note that the timing of the maximum groundwater impact will be constant for a given model simulation regardless of the input soil concentration.

- 3) Determine the target maximum contaminant flux (ug/l) for that month's volume of recharge water (volume groundwater recharge X desired recharge water MCL).
- 4) Adjust the input soil concentration until the contaminant flux reported for the month of maximum groundwater impact matches the target maximum flux.

The model is now calibrated. An example SESOIL output file for a calibrated model is presented in Attachment 1.

The maximum, month-averaged contaminant concentration in the recharge water will typically occur in the first or second month of groundwater impact. (Unless pure-phase product is entering the groundwater, the concentration of the contaminant in the recharge water be highest immediately following groundwater impact and then show a progressive decrease over time. Leachate contaminant concentrations may not appear to be highest during the first month of groundwater impact because the concentration is month-averaged and the leachate may not have arrived until some point late in that month.)

Provided that the input contaminant concentration does not lead to the presence of pure phase contaminant in the model impacted layer (i.e., the soil is oversaturated), the relationship between the input soil concentration and the output concentration of the contaminant in the recharge water is linear and the model is easy to calibrate. The calibrated, input soil contaminant concentration ( $C_c$ ) is simply the input soil concentration ( $C_i$ ) times the ratio of the target contaminant flux ( $F_t$ ) over the reported contaminant flux ( $F_r$ ):

$$C_c = C_i \times (F_t/F_r).$$

This quick and easy technique for calibrating a model simulation generally holds true for relatively mobile contaminants with low target MCLs and model groundwater depths of twenty meters or less. When input soil concentrations must be increased to above saturation levels in order to produce the target groundwater impact, however, then calibration of the model becomes increasingly more "hit-and-miss" and time consuming. In practice, model results are accepted as calibrated if contaminant concentrations in the recharge water were within one or two percent of the target MCL, since calibrating the model exactly to MCLs concentrations can be very challenging and adds only negligibly to the accuracy of the model output.

## **EXTRACTION OF SOIL ACTION LEVELS FROM SESOIL OUTPUT**

As described above, it is generally a simple and quick task to adjust the input pollutant

soil concentration until the desired MCL is reached in the recharge water. But is the calibrated, input soil concentration actually the soil concentration that led to the reported groundwater impact? Not necessarily, depending on the impacted-site scenario that was to be evaluated. Techniques to extract the "true" soil contaminant concentration from the SESOIL output file are described below.

### **Review of Model Impacted-Site Scenario**

For both Tier 1 and Tier 2 modeling purposes, the release associated with the detection of impacted soil at a site is assumed to have occurred several months or even several years prior to its discovery. This is a key point. Because it is assumed that the release occurred some time before its discovery and the followup subsurface investigation, it is appropriate to further assume that surface water, usually in the form of rainfall, has had time to infiltrate into the impacted layer and mobilize a dissolved-phase plume of the contaminant.

As a conservative but not unrealistic approach, the leading edge of this mobilized, dissolved-phase plume is further assumed to be coincident with the base of the impacted layer, as determined from the subsurface investigation at the site (or two meters depth in the example given in Attachment 1). From the perspective of completing a site investigation this may seem like a insignificant point but, as pointed out below, from a modeling perspective the difference is important.

### **The SESOIL Black Box**

The SESOIL application is quite capable of modeling the impacted-site scenario described above if the output data are evaluated correctly. Refer again to the example model output in Attachment 1 and to Figure 1. At the point that the SESOIL simulation is initiated ("Time 0" in Figure 1), the concentration of the contaminant in the impacted soil layer matches that input into the model and, importantly, a dissolved-phase plume of the contaminant has not yet been mobilized. As the model simulation progresses, surface water infiltrates through the top of the impacted layer and a dissolved-phase plume begins to move downward. The position of the plumes leading edge at the end of each month is somewhat ambiguously reported as "pollutant depth" in the SESOIL output file.

At some point in the model simulation the plume passes through the base of the model impacted layer ("Time 1" in Figure 1). In the example model presented in Attachment 1, the leading edge of the benzene plume passed through the base of the two-meter-thick, impacted soil layer during the fourth month of the first year of the model simulation (plume depth exceeds two meters). The plume passed through the base of the underlying, one-meter-thick "clean" soil layer very early in the 8<sup>th</sup> month of the 1<sup>st</sup> year (plume depth exceeds three meters), entered the basaltic bedrock and eventually reached groundwater during the 1<sup>st</sup> month of the 3<sup>rd</sup> year (plume depth exceeds twelve meters). The highest, month-averaged concentration of benzene in the leachate occurred in the 2<sup>nd</sup> month of the 3<sup>rd</sup> year (Time 2 in the attachment data, see also

Figure 1).

### Calculation of Soil Action Levels for Leachate Impact

By closely evaluating the example SESOIL model output, the relationship between the SESOIL simulation and the desired impacted-site scenario becomes more clear. The desired model scenario begins at the point in time that the pollutant front passes through the base of the impacted layer (i.e., Time 1, or during the fourth month of the example model given the attachment), not at the very beginning of the simulation (Time 0).

Careful evaluation of the example SESOIL output reveals that during this "lag time" between Time 0 and Time 1 the total mass of the contaminant in the model impacted layer was being reduced by volatilization and biodegradation. The actual contaminant mass present in the model impacted soil layer at the point that the dissolved-phase plume breaches the base of the model impacted layer is represented by the sum of the individual contaminant-phase masses reported for the corresponding year and month in the "Pollutant Mass Distribution In Soil Column" section of the output file.

The corresponding concentration of the contaminant in the model, impacted layer, or the preliminary soil action level for leachate impact on groundwater ( $SAL_{gw}$ ), is determined by dividing the total contaminant mass reported in the layer for that month by the mass of the model impacted layer:

$$SAL_{gw} = (M_d + M_s + M_v)/(A \times T \times d)$$

where " $M_d$ ", " $M_s$ ", and " $M_v$ ", correspond to the dissolved, sorbed, and vapor phases of the total contaminant mass as reported in the output file and "A", "T", and "d" correspond to the area, thickness, and density of the model impacted layer as input into the model. Tier 1 soil action levels generated for leachate-impact concerns are given in Appendix A. For Tier 1 and Tier 2 purposes, the maximum allowable soil action level is the theoretical, Tier 1 saturation limit of that contaminant in soil (see Appendix F). Note that when calibration of a model simulation required that the contaminant soil saturation level be exceeded then no soil action level for leachate-impact concerns was generated ("N/A" in Table 1 of Appendix F).

The procedures outlined above must be followed for the calculation of SESOIL-generated, Tier 2 soil action levels. The soil concentration that is initially input into the model for each contaminant is simply an artifact of the default impacted-site scenario incorporated into the SESOIL application and is only indirectly correlative to the resultant groundwater impact. As noted in the example given in the attachment, the difference between the input soil concentration and the actual soil action level generated with SESOIL can be very significant, especially for contaminants with a high volatility and/or rapid biodegradation rate. More importantly, the procedures used to generate the Tier 1 and Tier 2 soil action level more completely and accurately relate the SESOIL simulation to the desired impacted-site scenario.

## Calculation of Additional Contaminant Saturation Limits in Soil

A contaminants saturation level in soil is defined as the concentration at which the contaminant is no longer able to partition into separate dissolved, sorbed, and/or vapor phases and a free-product phase remains present. This is marked in the SESOIL output by the reporting of "pure-phase" product in the model impacted layer (i.e., the model impacted layer becomes oversaturated). The saturation level of a contaminant is a function of the contaminants physio-chemical characteristics and the physical properties of the model impacted soil layer.

Procedure to calculate soil saturation limits for contaminants are as follows:

- Step 1. Configure the application to run the Tier 1 model scenario as outlined in Chapter 1, Table 1-3 and Appendix C. In the "Soil Column Properties" module, input two identical soil layers with a permeability of  $1\text{E-}07$  cm/sec<sup>2</sup>. Input a value of "1" for all of the default factors. Only the uppermost layer is actually needed but SESOIL requires that at least two layers be input into any given model.
- Step 2. Input the physio-chemical constants for the contaminant in the appropriate module (check with DOH for information on contaminant constants).
- Step 3. Oversaturate the upper soil layer by inputting a soil concentration of 1,000,000ug/g for the uppermost layer in pollutant loading module and run the model. (To save time, only input a model simulation time of 1 year in the first module of the application.)
- Step 4. Refer to the data presented for the first month of the "Pollutant Mass Distribution in Column" portion of the output file. A "pure phase" fraction of contaminant should be reported, indicating that the soil is oversaturated with the contaminant. (If not, check to make sure the input soil concentration was 1,000,000ug/g.)

The contaminant saturation concentrations ( $C_s$ ) is determined by dividing the total dissolved, sorbed, and vapor phase mass of the contaminant reported by the mass of the soil in the same manner that soil action levels are calculated:

$$C_s = (M_d + M_s + M_v)/(A \times T \times d)$$

again where " $M_d$ ", " $M_s$ ", and " $M_v$ ", correspond to the dissolved, sorbed, and vapor phases of the total contaminant mass as reported in the output file and " $A$ ", " $T$ ", and " $d$ " correspond to the area, thickness, and density of the model impacted layer as input into the model.



Impacted sites commonly involve complex mixtures of contaminants (e.g., petroleum releases). For application to these types of impacted-site scenarios, the saturation calculated assume that the equivalent of no more than 0.1 weight percent organic carbon is available in the soil for sorption of any given contaminant. This is assumed to be appropriate for most petroleum release sites. Note that theoretical saturation levels presented for common petroleum constituents are intended to address potential mobilization of the free product mixture as a whole rather remobilization of specific contaminants.

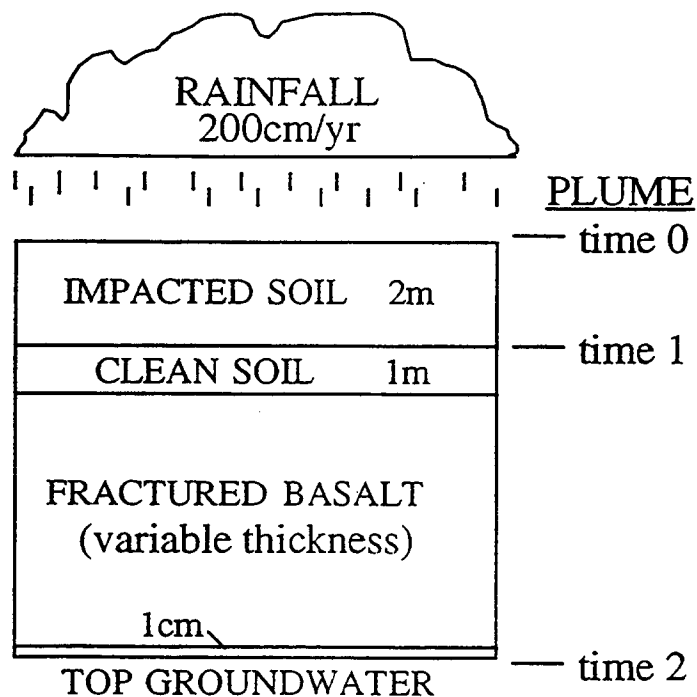


Figure 1. Migration of dissolved-phase plume through vadose zone. Time 0: Model simulation begins, dissolved-phase plume initiates at top of impacted layer. Time 1: Dissolved-phase plume passes through base of model impacted layer. Time 1 to Time 2: Dissolved-phase plume migrates through clean soil layer and basaltic bedrock to groundwater. Time 2: Dissolved-phase plume impacts groundwater at maximum, month-averaged contaminant concentration.

**ATTACHMENT D1**  
**EXAMPLE SESOIL OUTPUT**

## EXAMPLE SESOIL OUTPUT

MODEL TYPE: Generic, four-layer model (refer to Figure 1 in text)

CONTAMINANT: Benzene

GROUNDWATER TYPE: Drinking water resource

CONTAMINANT MCL: 0.005ug/ml

CLIMATE DATA: Ahuimanu climate station (rainfall adjusted to 200cm/year)

THICKNESS OF IMPACTED LAYER: 2 meters

DENSITY OF IMPACTED SOIL: 1.5g/cm<sup>3</sup>

MODEL AREA: 1,000cm<sup>2</sup>

DEPTH TO GROUNDWATER: 10 meters (equals thickness of lower sediment layer plus thickness of underlying basalt layer)

### MODEL SIMULATION RESULTS:

1. Maximum, month-averaged, impact of leachate on groundwater (Time 2):  
  
3<sup>rd</sup> year, 2<sup>nd</sup> month (page D1-14, benzene runoff mass/volume recharge water).
2. Volume recharge water for Time 2:  
  
= model area x groundwater runoff  
= 1,000cm<sup>2</sup> x 6,707cm  
= 6,707ml (page D1-13).
3. Target maximum groundwater benzene runoff mass for Time 2:  
  
= Benzene MCL x recharge water volume  
= 0.005mg/l x 6,707ml  
= 33.54ug/mo (Compare to page D1-14).
4. Calibrated input soil concentration:  
  
0.093ug/g (pg D1-5, benzene runoff mass = 33.72mg/l)

5. Initiation of model scenario (Time 1):  
  
1<sup>st</sup> year, 4<sup>th</sup> month (page D1-8, dissolved-phase plume migrates beyond two meters depth.)
6. Mass of benzene in model impacted layer at Time 1:  
  
= 7,997ug (page D1-7)
7. Concentration of benzene in model impacted layer Time 1:  
  
= mass benzene/mass soil  
= 7,997ug/(1,000cm<sup>2</sup> x 200cm x 1.5g/cm<sup>3</sup>)  
= 7,997ug/300,000g  
= 0.027ug/g (see page D1-7).
8. SESOIL-generated soil action level: 0.027ug/g (see Table 1a in Appendix F).

\*\*\*\*\*  
SESOL-84 : SEASONAL CYCLES OF WATER, SEDIMENT, AND POLLUTANTS IN SOIL ENVIRONMENTS

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VERSION : SEPTEMBER 1986

\*\*\*\*\*

\*\*\*\*\* MONTHLY SESOIL MODEL OPERATION \*\*\*\*\*  
MONTHLY SITE SPECIFIC SIMULATION

REGION : AHUIMANU LOOP 839.12  
SOIL TYPE : saprolite  
COMPOUND : benzene  
WASHLOAD DATA :  
APPLICATION AREA: EXAMPLE - RESIDUAL BENZENE IN IMPACTED SOIL

# GENERAL INPUT PARAMETERS

=====

## -- SOIL INPUT PARAMETERS --

SOIL DENSITY (G/CM**3):	1.50
INTRINSIC PERMEABILITY (CM**2):	.000
DISCONNECTEDNESS INDEX (-):	3.50
POROSITY (-):	.300
ORGANIC CARBON CONTENT (%):	.100
CATION EXCHANGE CAPACITY (MILLI EQ./100G DRY SOIL):	.000
FREUNDLICH EXPONENT (-):	1.00

## -- CHEMICAL INPUT PARAMETERS --

SOLUBILITY (UG/ML):	.180E+04
DIFFUSION COEFFICIENT IN AIR (CM**2/SEC):	.880E-01
HENRYS LAW CONSTANT (M**3-ATM/MOLE):	.550E-02
ADSORPTION COEFFICIENT ON ORGANIC CARBON(KOC):	65.0
ADSORPTION COEFFICIENT ON SOIL (K):	.000
MOLECULAR WEIGHT (G/MOL):	78.0
VALENCE (-):	.000
NEUTRAL HYDROLYSIS CONSTANT (/DAY):	.000
BASE HYDROLYSIS CONSTANT (L/MOL-DAY):	.000
ACID HYDROLYSIS CONSTANT (L/MOL-DAY):	.000
DEGRADATION RATE IN MOISTURE (/DAY):	.620E-02
DEGRADATION RATE ON SOIL (/DAY):	.310E-02
LIGAND-POLLUTANT STABILITY CONSTANT (-):	.000
NO. MOLES LIGAND/MOLE POLLUTANT (-):	.000
LIGAND MOLECULAR WEIGHT (G/MOL):	.000

## -- APPLICATION INPUT PARAMETERS --

NUMBER OF SOIL LAYERS:	4			
YEARS TO BE SIMULATED:	3			
AREA (CM**2):	0.100E+04			
APPLICATION AREA LATITUDE (DEG.):	21.4			
SPILL (1) OR STEADY APPLICATION (0):	1			
DEPTHS (CM):	0.20E+03	0.10E+03	0.90E+03	1.0
NUMBER OF SUBLAYERS/LAYER	1	1	1	1
PH (CM):	0.00	0.00	0.00	0.00
INTRINSIC PERMEABILITIES (CM**2):	0.10E-06	0.10E-06	0.10E-05	0.10E-05
KDEL RATIOS (-):	1.0	1.0	1.0	
KDES RATIOS (-):	1.0	1.0	1.0	
OC RATIOS (-):	1.0	0.10E-02	0.10E-02	
CEC RATIOS (-):	1.0	1.0	1.0	
FRN RATIOS(-):	1.0	1.0	1.0	
ADS RATIOS(-):	1.0	1.0	1.0	

YEAR . 1 MONTHLY INPUT PARAMETERS  
=====

-- CLIMATIC INPUT PARAMETERS --

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
TEMP. (DEG C)	25.000	24.000	23.000	22.000	22.000	22.000	23.000	24.000	25.000	25.000	25.000	25.000
CLOUD CVR (FRAC.)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
REL. HUM. (FRAC.)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ALBEDO (-)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EVAPOT. (CM/DAY)	0.210	0.240	0.280	0.390	0.220	0.280	0.270	0.180	0.140	0.140	0.160	0.140
PRECIP. (CM)	12.020	14.060	15.900	22.540	12.880	16.370	15.320	10.680	7.870	8.100	9.190	7.920
M.TIME RAIN(DAYS)	0.310	0.360	0.430	0.500	0.350	0.330	0.360	0.270	0.260	0.290	0.260	0.230
M. STORM NO. (-)	12.200	12.190	11.130	10.000	10.140	12.640	13.600	13.000	11.470	12.470	12.790	11.800
M. SEASON (DAYS)	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400	30.400

-- POLLUTANT INPUT PARAMETERS --

TIME 0: ONE-TIME, INSTANTANEOUS POLLUTANT INPUT.  
 Input = 27.9ug/cm<sup>2</sup> dispersed through 200cm depth  
 = 0.1395ug/cm<sup>3</sup>  
 = 0.093ug/g (input soil concentration)

POL. INP-1 (UG/CM**2)	2.79E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TRANSFORMD-1 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SINKS-1 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LIG.INPUT-1 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VOLATILIZATION MULT.-1	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01
SURFACE RUNOFF MULT.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
POL. IN RAIN (FRAC-SL)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
POL. INP-2 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TRANSFORMD-2 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SINKS-2 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LIG.INPUT-2 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VOLATILIZATION MULT.-2	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01
POL. INP-3 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TRANSFORMD-3 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SINKS-3 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LIG.INPUT-3 (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VOLATILIZATION MULT.-3	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01
POL. INP-L (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TRANSFORMD-L (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SINKS-L (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LIG.INPUT-L (UG/CM**2)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VOLATILIZATION MULT.-L	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01	2.00E-01



YEAR - 2

.. CLIMATIC INPUT PARAMETERS ARE SAME AS LAST YEAR

.. POLLUTANT INPUT PARAMETERS ..

[illegible]

=====

YEAR - 3

∴ CLIMATIC INPUT PARAMETERS ARE SAME AS LAST YEAR

... POLLUTANT INPUT PARAMETERS ARE SAME AS LAST YEAR

YEAR - 1 MONTHLY RESULTS (OUTPUT)

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-- HYDROLOGIC CYCLE COMPONENTS --

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MOIS. IN L1 (%)	1.920	2.010	2.070	2.310	2.010	2.130	2.070	1.890	1.710	1.710	1.770	1.710
MOIS. BELOW L1 (%)	1.920	2.010	2.070	2.310	2.010	2.130	2.070	1.890	1.710	1.710	1.770	1.710
PRECIPITATION (CM)	12.211	14.093	15.827	22.498	12.779	16.462	15.403	10.698	7.981	8.161	9.330	8.101
NET INFILT. (CM)	12.211	14.093	15.827	22.498	12.779	16.462	15.403	10.698	7.981	8.161	9.330	8.101
EVAPOTRANS. (CM)	6.384	7.296	8.512	11.856	6.688	8.512	8.208	5.472	4.256	4.256	4.864	4.256
MOIS. RETEN (CM)	-0.030	0.090	0.060	0.240	-0.300	0.120	-0.060	-0.180	-0.180	0.000	0.060	-0.060
SUR. RUNOFF (CM)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRW. RUNOFF (CM)	5.857	6.707	7.255	10.402	6.392	7.830	7.255	5.406	3.905	3.905	4.406	3.905
YIELD (CM)	5.857	6.707	7.255	10.402	6.392	7.830	7.255	5.406	3.905	3.905	4.406	3.905
PAU/MPA (GZU)	1.016	1.002	0.995	0.998	0.992	1.006	1.005	1.002	1.014	1.007	1.015	1.023
PA/MPA (GZ)	1.016	1.002	0.995	0.998	0.992	1.006	1.005	1.002	1.014	1.007	1.015	1.023

-- POLLUTANT MASS INPUT TO COLUMN (UG) --

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
PRECIP.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD UPPER	2.790E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD ZONE 2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD ZONE 3	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD LOWER	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL INPUT	2.790E+04	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
UPPER SOIL ZONE: SUBLAYER 1												
VOLATILIZED	5.494E+03	4.034E+03	2.981E+03	2.149E+03	1.508E+03	9.770E+02	6.523E+02	5.155E+02	4.251E+02	3.320E+02	2.528E+02	1.959E+02
DEGRAD MOIS	4.777E+02	3.698E+02	2.825E+02	2.276E+02	1.341E+02	9.338E+01	6.190E+01	4.387E+01	3.216E+01	2.515E+01	1.996E+01	1.484E+01
DEGRAD SOIL	1.213E+03	8.971E+02	6.654E+02	4.805E+02	3.252E+02	2.138E+02	1.458E+02	1.132E+02	9.170E+01	7.173E+01	5.493E+01	4.231E+01
IN SOIL MOI	2.215E+03	1.717E+03	1.313E+03	1.000E+03	5.894E+02	4.053E+02	2.861E+02	2.121E+02	1.537E+02	1.191E+02	9.397E+01	7.011E+01
ADS ON SOIL	1.125E+04	8.331E+03	6.184E+03	4.223E+03	2.859E+03	1.855E+03	1.348E+03	1.095E+03	8.767E+02	6.791E+02	5.173E+02	3.998E+02
IN SOIL AIR	7.245E+03	5.365E+03	3.987E+03	2.774E+03	1.898E+03	1.227E+03	8.678E+02	7.068E+02	5.677E+02	4.391E+02	3.341E+02	2.585E+02

--- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) --- NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED

TOTAL CONTAMINANT MASS IN SOIL AT TIME 1 = 7,997ug benzene in 200,000cm<sup>3</sup> soil  
= 0.027ug/g

SOIL ZONE 2: SUBLAYER 1

DIFFUSED UP	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
DEGRAD MOIS	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
DEGRAD SOIL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IN SOIL MOI	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ADS ON SOIL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IN SOIL AIR	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

SOIL ZONE 3: SUBLAYER 1

DEGRAD MOIS	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
DEGRAD SOIL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IN SOIL MOI	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
ADS ON SOIL	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
IN SOIL AIR	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

LOWER SOIL ZONE: SUBLAYER 1

... POLLUTANT CONCENTRATIONS (UG/ML) OR (UG/G) -- NOTE: IF CONCENTRATIONS ARE ZERO FOR EACH MONTH, THEY ARE NOT PRINTED ...

UPPER SOIL ZONE: SUBLAYER 1

MOISTURE 5.771E-01 4.272E-01 3.171E-01 2.166E-01 1.466E-01 9.515E-02 6.912E-02 5.613E-02 4.496E-02 3.482E-02 2.655E-02 2.050E-02  
%SOLUBILITY 3.206E-02 2.374E-02 1.762E-02 1.203E-02 8.146E-03 5.286E-03 3.840E-03 3.119E-03 2.498E-03 1.935E-03 1.475E-03 1.139E-03  
ADSORBED 3.751E-02 2.777E-02 2.061E-02 1.408E-02 9.531E-03 6.185E-03 4.493E-03 3.649E-03 2.922E-03 2.264E-03 1.726E-03 1.333E-03  
SOIL AIR 1.290E-01 9.583E-02 7.137E-02 5.008E-02 3.391E-02 2.200E-02 1.554E-02 1.257E-02 1.003E-02 7.760E-03 5.917E-03 4.569E-03

SOIL ZONE 2: SUBLAYER 1

MOISTURE 0.000E+00 0.000E+00 0.000E+00 3.352E-02 6.766E-02 9.290E-02 9.341E-02 7.590E-02 5.650E-02 4.303E-02 3.280E-02 2.523E-02  
%SOLUBILITY 0.000E+00 0.000E+00 0.000E+00 1.862E-03 3.759E-03 5.161E-03 5.182E-03 4.217E-03 3.139E-03 2.391E-03 1.822E-03 1.402E-03  
ADSORBED 0.000E+00 0.000E+00 0.000E+00 2.179E-03 4.398E-03 6.038E-03 6.072E-03 4.934E-03 3.672E-03 2.797E-03 2.132E-03 1.640E-03  
SOIL AIR 0.000E+00 0.000E+00 0.000E+00 7.753E-03 1.565E-02 2.148E-02 2.099E-02 1.700E-02 1.261E-02 9.588E-03 7.310E-03 5.622E-03

SOIL ZONE 3: SUBLAYER 1

MOISTURE 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 5.325E-04 2.524E-03 3.966E-03 5.112E-03 5.835E-03  
%SOLUBILITY 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 2.958E-05 1.402E-04 2.203E-04 2.840E-04 3.241E-04  
ADSORBED 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 3.461E-08 1.640E-07 2.578E-07 3.323E-07 3.792E-07  
SOIL AIR 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 1.193E-04 5.633E-04 8.837E-04 1.139E-03 1.300E-03

LOWER SOIL ZONE:

POL DEP CM 4.411E+01 9.476E+01 1.514E+02 2.143E+02 2.347E+02 2.607E+02 2.853E+02 3.072E+02 3.456E+02 3.843E+02 4.279E+02 4.665E+02

TIME 1 (1<sup>ST</sup> year, 4<sup>th</sup> month)

Dissolved-phase plume passes through base  
of model impacted layer.

YEAR - 1 ANNUAL SUMMARY REPORT

-- TOTAL INPUTS (UG) --  
 UPPER SOIL ZONE 2.790E+04  
 SOIL ZONE 2 0.000E+00  
 SOIL ZONE 3 0.000E+00  
 LOWER SOIL ZONE 0.000E+00

-- HYDROLOGIC CYCLE COMPONENTS --  
 AVERAGE SOIL MOISTURE ZONE 1 (%) 1.942  
 AVERAGE SOIL MOISTURE BELOW ZONE 1 (%) 1.942  
 TOTAL PRECIPITATION (CM) 153.544  
 TOTAL INFILTRATION (CM) 153.544  
 TOTAL EVAPOTRANSPIRATION (CM) 80.560  
 TOTAL SURFACE RUNOFF (CM) 0.000  
 TOTAL GRW RUNOFF (CM) 73.224  
 TOTAL MOISTURE RETENTION (CM) -0.240  
 TOTAL YIELD (CM) 73.224

-- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) --  
 NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED

FOR FINAL MASS IN SOIL MOI., ADS. ON SOIL, SOIL AIR, IMMOBIL CEC, COMPLEXED, AND PURE PHASE FOR EACH  
 SUBLAYER, SEE ABOVE (MONTH SEP)

UPPER SOIL ZONE: SUBLAYER 1  
 TOTAL VOLATILIZED 1.952E+04  
 TOTAL DEGRADED (MOISTURE) 1.783E+03  
 TOTAL DEGRADED (SOIL) 4.315E+03

SOIL ZONE 2: SUBLAYER 1  
 TOTAL DIFFUSED (UP) 1.257E+03  
 TOTAL DEGRADED (MOISTURE) 1.803E+02  
 TOTAL DEGRADED (SOIL) 4.574E+02

SOIL ZONE 3: SUBLAYER 1  
 TOTAL DEGRADED (MOISTURE) 4.367E+01  
 TOTAL DEGRADED (SOIL) 1.232E-01

LOWER SOIL ZONE: SUBLAYER 1

-- AVERAGE POLLUTANT CONCENTRATIONS --  
 NOTE: ONLY NON-ZERO VALUES ARE PRINTED --

UPPER SOIL ZONE: SUBLAYER 1  
 SOIL MOISTURE (UG/ML) 1.693E-01  
 ADSORBED SOIL (UG/G) 1.101E-02  
 SOIL AIR (UG/ML) 3.822E-02  
 SOIL ZONE 2: SUBLAYER 1  
 SOIL MOISTURE (UG/ML) 4.341E-02  
 ADSORBED SOIL (UG/G) 2.822E-03  
 SOIL AIR (UG/ML) 9.834E-03  
 SOIL ZONE 3: SUBLAYER 1  
 SOIL MOISTURE (UG/ML) 1.497E-03  
 ADSORBED SOIL (UG/G) 9.733E-08  
 SOIL AIR (UG/ML) 3.338E-04  
 LOWER SOIL ZONE:  
 MAX. POLL. DEPTH (M) 4.665E+00

# YEAR - 2 MONTHLY RESULTS (OUTPUT)

## --- HYDROLOGIC CYCLE COMPONENTS ---

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MOIS. IN L1 (%)	1.890	2.010	2.070	2.310	2.010	2.130	2.070	1.890	1.710	1.710	1.770	1.710
MOIS. BELOW L1 (%)	1.890	2.010	2.070	2.310	2.010	2.130	2.070	1.890	1.710	1.710	1.770	1.710
PRECIPITATION (CM)	12.107	14.123	15.827	22.498	12.779	16.462	15.403	10.698	7.981	8.161	9.330	8.101
NET INFILT. (CM)	12.107	14.123	15.827	22.498	12.779	16.462	15.403	10.698	7.981	8.161	9.330	8.101
EVAPOTRANS. (CM)	6.384	7.296	8.512	11.856	6.688	8.512	8.208	5.472	4.256	4.256	4.864	4.256
MOIS. RETEN (CM)	0.180	0.120	0.060	0.240	-0.300	0.120	-0.060	-0.180	-0.180	0.000	0.060	-0.060
SUR. RUNOFF (CM)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRW. RUNOFF (CM)	5.543	6.707	7.255	10.402	6.392	7.830	7.255	5.406	3.905	3.905	4.406	3.905
YIELD (CM)	5.543	6.707	7.255	10.402	6.392	7.830	7.255	5.406	3.905	3.905	4.406	3.905
PAU/MPA (GZU)	1.007	1.004	0.995	0.998	0.992	1.006	1.005	1.002	1.014	1.007	1.015	1.023
PA/MPA (GZ)	1.007	1.004	0.995	0.998	0.992	1.006	1.005	1.002	1.014	1.007	1.015	1.023

## --- POLLUTANT MASS INPUT TO COLUMN (UG) ---

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
PRECIP.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD UPPER	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD ZONE 2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD ZONE 3	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD LOWER	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL INPUT	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

## --- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) --- NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED

### UPPER SOIL ZONE: SUBLAYER 1

VOLATILIZED	1.448E+02	1.063E+02	7.814E+01	5.527E+01	4.258E+01	3.134E+01	2.335E+01	1.870E+01	1.559E+01	1.295E+01	1.077E+01	9.296E+00
DEGRAD MOIS	1.235E+01	9.747E+00	7.405E+00	5.855E+00	3.786E+00	2.995E+00	2.216E+00	1.591E+00	1.180E+00	9.809E+00	8.508E+01	7.043E+01
DEGRAD SOIL	3.186E+01	2.365E+01	1.744E+01	1.236E+01	9.185E+00	6.857E+00	5.220E+00	4.106E+00	3.363E+00	2.797E+00	2.344E+00	2.008E+00
IN SOIL MOI	5.761E+01	4.526E+01	3.424E+01	2.653E+01	1.776E+01	1.392E+01	1.042E+01	7.779E+00	5.779E+00	4.839E+00	4.213E+00	3.532E+00
ADS ON SOIL	2.973E+02	2.196E+02	1.613E+02	1.120E+02	8.615E+01	6.373E+01	4.909E+01	3.955E+01	3.296E+01	2.760E+01	2.321E+01	2.015E+01
IN SOIL AIR	1.916E+02	1.414E+02	1.040E+02	7.356E+01	5.720E+01	4.213E+01	3.161E+01	2.554E+01	2.134E+01	1.784E+01	1.498E+01	1.303E+01

### SOIL ZONE 2: SUBLAYER 1

DIFFUSED UP	6.934E+01	5.360E+01	4.096E+01	3.108E+01	2.362E+01	1.820E+01	1.517E+01	1.321E+01	1.182E+01	1.064E+01	9.637E+00	8.953E+00
DEGRAD MOIS	7.653E+00	6.102E+00	4.673E+00	3.750E+00	2.418E+00	1.933E+00	1.468E+00	1.077E+00	8.134E+01	6.919E+01	6.156E+01	5.217E+01
DEGRAD SOIL	1.974E+01	1.480E+01	1.101E+01	7.915E+00	5.856E+00	4.424E+00	3.458E+00	2.778E+00	2.319E+00	1.973E+00	1.696E+00	1.488E+00
IN SOIL MOI	3.587E+01	2.843E+01	2.167E+01	1.713E+01	1.131E+01	9.102E+00	6.998E+00	5.238E+00	4.027E+00	3.455E+00	3.088E+00	2.644E+00
ADS ON SOIL	1.851E+02	1.380E+02	1.021E+02	7.231E+01	5.488E+01	4.167E+01	3.297E+01	2.703E+01	2.297E+01	1.970E+01	1.701E+01	1.508E+01
IN SOIL AIR	1.193E+02	8.883E+01	6.582E+01	4.749E+01	3.643E+01	2.755E+01	2.123E+01	1.745E+01	1.487E+01	1.274E+01	1.098E+01	9.749E+00

### SOIL ZONE 3: SUBLAYER 1

DIFFUSED UP	0.000E+00	0.000E+00	0.000E+00	0.000E+00	1.944E+00	4.548E+00	6.442E+00	7.732E+00	8.509E+00	8.625E+00	8.473E+00	8.449E+00
DEGRAD MOIS	1.939E+01	2.251E+01	2.462E+01	2.775E+01	2.526E+01	2.620E+01	2.559E+01	2.302E+01	2.035E+01	1.946E+01	1.909E+01	1.766E+01
DEGRAD SOIL	5.002E+02	5.459E+02	5.799E+02	5.857E+02	6.128E+02	5.997E+02	6.028E+02	5.938E+02	5.804E+02	5.549E+02	5.259E+02	5.035E+02
IN SOIL MOI	1.099E+02	1.256E+02	1.355E+02	1.523E+02	1.352E+02	1.397E+02	1.356E+02	1.213E+02	1.070E+02	1.022E+02	1.002E+02	9.263E+01
ADS ON SOIL	5.671E+01	6.092E+01	6.383E+01	6.428E+01	6.559E+01	6.396E+01	6.389E+01	6.260E+01	6.105E+01	5.831E+01	5.523E+01	5.283E+01
IN SOIL AIR	3.654E+02	3.922E+02	4.115E+02	4.222E+02	4.355E+02	4.238E+02	4.114E+02	4.042E+02	3.953E+02	3.770E+02	3.564E+02	3.416E+02

### LOWER SOIL ZONE: SUBLAYER 1

-- POLLUTANT CONCENTRATIONS (UG/ML) OR (UG/G) -- NOTE: IF CONCENTRATIONS ARE ZERO FOR EACH MONTH, THEY ARE NOT PRINTED --

UPPER SOIL ZONE: SUBLAYER 1  
MOISTURE 1.525E-02 1.126E-02 8.272E-03 5.744E-03 4.418E-03 3.268E-03 2.517E-03 2.028E-03 1.690E-03 1.415E-03 1.190E-03 1.033E-03  
%SOLUBILITY 8.469E-04 6.256E-04 4.596E-04 3.191E-04 2.454E-04 1.816E-04 1.399E-04 1.127E-04 9.389E-05 7.863E-05 6.614E-05 5.739E-05  
ADSORBED 9.909E-04 7.319E-04 5.377E-04 3.733E-04 2.872E-04 2.124E-04 1.636E-04 1.318E-04 1.099E-04 9.200E-05 7.738E-05 6.715E-05  
SOIL AIR 3.408E-03 2.526E-03 1.862E-03 1.328E-03 1.022E-03 7.559E-04 5.658E-04 4.543E-04 3.772E-04 3.154E-04 2.653E-04 2.302E-04

SOIL ZONE 2: SUBLAYER 1  
MOISTURE 1.898E-02 1.415E-02 1.047E-02 7.416E-03 5.629E-03 4.274E-03 3.381E-03 2.772E-03 2.355E-03 2.021E-03 1.745E-03 1.546E-03  
%SOLUBILITY 1.055E-03 7.860E-04 5.817E-04 4.120E-04 3.127E-04 2.374E-04 1.879E-04 1.540E-04 1.309E-04 1.123E-04 9.695E-05 8.591E-05  
ADSORBED 1.234E-03 9.197E-04 6.806E-04 4.820E-04 3.659E-04 2.778E-04 2.198E-04 1.802E-04 1.531E-04 1.314E-04 1.134E-04 1.005E-04  
SOIL AIR 4.243E-03 3.173E-03 2.356E-03 1.715E-03 1.302E-03 9.884E-04 7.600E-04 6.209E-04 5.257E-04 4.503E-04 3.889E-04 3.446E-04

SOIL ZONE 3: SUBLAYER 1  
MOISTURE 6.462E-03 6.942E-03 7.274E-03 7.325E-03 7.475E-03 7.289E-03 7.281E-03 7.133E-03 6.957E-03 6.645E-03 6.294E-03 6.020E-03  
%SOLUBILITY 3.590E-04 3.857E-04 4.041E-04 4.070E-04 4.153E-04 4.049E-04 4.045E-04 3.963E-04 3.865E-04 3.692E-04 3.497E-04 3.345E-04  
ADSORBED 4.200E-07 4.512E-07 4.728E-07 4.761E-07 4.859E-07 4.738E-07 4.733E-07 4.637E-07 4.522E-07 4.319E-07 4.091E-07 3.913E-07  
SOIL AIR 1.444E-03 1.557E-03 1.637E-03 1.694E-03 1.729E-03 1.686E-03 1.636E-03 1.598E-03 1.553E-03 1.481E-03 1.403E-03 1.342E-03

LOWER SOIL ZONE:

POL DEP CM 5.212E+02 5.856E+02 6.556E+02 7.515E+02 8.105E+02 8.832E+02 9.526E+02 1.004E+03 1.043E+03 1.081E+03 1.125E+03 1.163E+03

YEAR - 2 ANNUAL SUMMARY REPORT

==  
 -- TOTAL INPUTS (UG) --  
 UPPER SOIL ZONE 0.000E+00  
 SOIL ZONE 2 0.000E+00  
 SOIL ZONE 3 0.000E+00  
 LOWER SOIL ZONE 0.000E+00

-- HYDROLOGIC CYCLE COMPONENTS --  
 AVERAGE SOIL MOISTURE ZONE 1 (%) 1.940  
 AVERAGE SOIL MOISTURE BELOW ZONE 1 (%) 1.940  
 TOTAL PRECIPITATION (CM) 153.470  
 TOTAL INFILTRATION (CM) 153.470  
 TOTAL EVAPOTRANSPIRATION (CM) 80.560  
 TOTAL SURFACE RUNOFF (CM) 0.000  
 TOTAL GRW RUNOFF (CM) 72.910  
 TOTAL MOISTURE RETENTION (CM) 0.000  
 TOTAL YIELD (CM) 72.910

-- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) --  
 NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED

FOR FINAL MASS IN SOIL MOI., ADS. ON SOIL, SOIL AIR, IMMOBIL CEC, COMPLEXED, AND PURE PHASE FOR EACH  
 SUBLAYER, SEE ABOVE (MONTH SEP)

UPPER SOIL ZONE: SUBLAYER 1  
 TOTAL VOLATILIZED 5.491E+02  
 TOTAL DEGRADED (MOISTURE) 4.966E+01  
 TOTAL DEGRADED (SOIL) 1.212E+02

SOIL ZONE 2: SUBLAYER 1  
 TOTAL DIFFUSED (UP) 3.062E+02  
 TOTAL DEGRADED (MOISTURE) 3.172E+01  
 TOTAL DEGRADED (SOIL) 7.747E+01

SOIL ZONE 3: SUBLAYER 1  
 TOTAL DIFFUSED (UP) 5.472E+01  
 TOTAL DEGRADED (MOISTURE) 2.709E+02  
 TOTAL DEGRADED (SOIL) 6.786E-01

LOWER SOIL ZONE: SUBLAYER 1

-- AVERAGE POLLUTANT CONCENTRATIONS --  
 NOTE: ONLY NON-ZERO VALUES ARE PRINTED

UPPER SOIL ZONE: SUBLAYER 1  
 SOIL MOISTURE (UG/ML) 4.840E-03  
 ADSORBED SOIL (UG/G) 3.146E-04  
 SOIL AIR (UG/ML) 1.092E-03

SOIL ZONE 2: SUBLAYER 1  
 SOIL MOISTURE (UG/ML) 6.228E-03  
 ADSORBED SOIL (UG/G) 4.049E-04  
 SOIL AIR (UG/ML) 1.406E-03

SOIL ZONE 3: SUBLAYER 1  
 SOIL MOISTURE (UG/ML) 6.925E-03  
 ADSORBED SOIL (UG/G) 4.501E-07  
 SOIL AIR (UG/ML) 1.563E-03

LOWER SOIL ZONE:  
 MAX. POLL. DEPTH (M) 1.163E+01

YEAR - 3 MONTHLY RESULTS (OUTPUT)

--- HYDROLOGIC CYCLE COMPONENTS ---

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
MOIS. IN L1 (%)	1.890	2.010	2.070	2.310	2.010	2.130	2.070	1.890	1.710	1.710	1.770	1.710
MOIS. BELOW L1 (%)	1.890	2.010	2.070	2.310	2.010	2.130	2.070	1.890	1.710	1.710	1.770	1.710
PRECIPITATION (CM)	12.107	14.123	15.827	22.498	12.779	16.462	15.403	10.698	7.981	8.161	9.330	8.101
NET INFILT. (CM)	12.107	14.123	15.827	22.498	12.779	16.462	15.403	10.698	7.981	8.161	9.330	8.101
EVAPOTRANS. (CM)	6.384	7.296	8.512	11.856	6.688	8.512	8.208	5.472	4.256	4.256	4.864	4.256
MOIS. RETEN (CM)	0.180	0.120	0.060	0.240	-0.300	0.120	-0.060	-0.180	-0.180	0.000	0.060	-0.060
SUR. RUNOFF (CM)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
GRW. RUNOFF (CM)	5.543	6.707	7.255	10.402	6.392	7.830	7.255	5.406	3.905	3.905	4.406	3.905
YIELD (CM)	5.543	6.707	7.255	10.402	6.392	7.830	7.255	5.406	3.905	3.905	4.406	3.905

VOLUME OF RECHARGE WATER ENTERING GROUNDWATER DURING TIME 2  
6.707cm deep over 1,000cm<sup>2</sup> = 6,707cm<sup>3</sup> or ml of recharge water

PAU/MPA (GZU)	1.007	1.004	0.995	0.998	0.992	1.006	1.005	1.002	1.014	1.007	1.015	1.023
PA/MPA (GZ)	1.007	1.004	0.995	0.998	0.992	1.006	1.005	1.002	1.014	1.007	1.015	1.023

--- POLLUTANT MASS INPUT TO COLUMN (UG) ---

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
PRECIP.	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD UPPER	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD ZONE 2	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD ZONE 3	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LOAD LOWER	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL INPUT	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

--- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) --- NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED

UPPER SOIL ZONE: SUBLAYER 1

VOLATILIZED	7.767E+00	6.499E+00	5.459E+00	4.407E+00	3.884E+00	3.275E+00	2.764E+00	2.479E+00	2.289E+00	2.073E+00	1.848E+00	1.680E+00
DEGRAD MOIS	6.624E-01	5.958E-01	5.173E-01	4.668E-01	4.354E-01	3.130E-01	2.623E-01	2.110E-01	1.731E-01	1.570E-01	1.460E-01	1.272E-01
DEGRAD SOIL	1.709E+00	1.445E+00	1.219E+00	9.853E-01	8.378E-01	7.165E-01	6.179E-01	5.442E-01	4.936E-01	4.478E-01	4.021E-01	3.628E-01
IN SOIL MOI	3.297E+00	2.958E+00	2.559E+00	2.259E+00	1.737E+00	1.552E+00	1.307E+00	1.071E+00	8.879E-01	8.042E-01	7.436E-01	6.513E-01
ADS ON SOIL	1.701E+01	1.435E+01	1.206E+01	9.536E+00	8.426E+00	7.106E+00	6.158E+00	5.525E+00	5.064E+00	4.587E+00	4.097E+00	3.714E+00
IN SOIL AIR	1.096E+01	9.241E+00	7.774E+00	6.263E+00	5.595E+00	4.697E+00	3.965E+00	3.568E+00	3.279E+00	2.966E+00	2.644E+00	2.402E+00

SOIL ZONE 2: SUBLAYER 1

DIFFUSED UP	8.050E+00	7.120E+00	6.146E+00	5.107E+00	4.509E+00	3.808E+00	3.258E+00	2.915E+00	2.661E+00	2.393E+00	2.129E+00	1.971E+00
DEGRAD MOIS	5.028E-01	4.611E-01	4.043E-01	3.686E-01	2.729E-01	2.475E-01	2.084E-01	1.675E-01	1.369E-01	1.238E-01	1.150E-01	1.001E-01
DEGRAD SOIL	1.297E+00	1.119E+00	9.523E-01	7.781E-01	6.621E-01	5.666E-01	4.910E-01	4.322E-01	3.903E-01	3.531E-01	3.168E-01	2.855E-01
IN SOIL MOI	2.533E+00	2.301E+00	2.008E+00	1.793E+00	1.369E+00	1.230E+00	1.041E+00	8.480E-01	7.009E-01	6.336E-01	5.859E-01	5.120E-01
ADS ON SOIL	1.307E+01	1.116E+01	9.457E+00	7.571E+00	6.648E+00	5.631E+00	4.903E+00	4.380E+00	3.997E+00	3.614E+00	3.228E+00	2.920E+00
IN SOIL AIR	8.422E+00	7.189E+00	6.098E+00	4.972E+00	4.411E+00	3.723E+00	3.157E+00	2.825E+00	2.588E+00	2.337E+00	2.083E+00	1.888E+00

SOIL ZONE 3: SUBLAYER 1

DIFFUSED UP	7.871E+00	6.875E+00	5.909E+00	4.805E+00	4.417E+00	3.735E+00	3.255E+00	2.958E+00	2.740E+00	2.458E+00	2.170E+00	1.971E+00
DEGRAD MOIS	1.812E-01	1.691E-01	1.498E-01	1.362E-01	1.041E-01	9.457E-02	8.131E-02	6.603E-02	5.428E-02	4.886E-02	4.506E-02	3.925E-02
DEGRAD SOIL	4.674E-02	4.103E-02	3.528E-02	2.876E-02	2.525E-02	2.165E-02	1.915E-02	1.704E-02	1.548E-02	1.393E-02	1.241E-02	1.119E-02
IN SOIL MOI	9.312E+01	8.492E+01	7.497E+01	6.709E+01	5.239E+01	4.721E+01	4.067E+01	3.339E+01	2.711E+01	2.494E+01	2.293E+01	2.003E+01
ADS ON SOIL	4.805E-01	4.120E-01	3.532E-01	2.832E-01	2.542E-01	2.162E-01	1.916E-01	1.723E-01	1.580E-01	1.422E-01	1.263E-01	1.143E-01
IN SOIL AIR	3.096E+02	2.653E+02	2.277E+02	1.860E+02	1.688E+02	1.429E+02	1.234E+02	1.113E+02	1.023E+02	9.197E+01	8.151E+01	7.387E+01



... POLLUTANT MASS DISTRIBUTION IN COLUMN (UG)CONTINUED...

LOWER SOIL ZONE: SUBLAYER 1  
 DIFFUSED UP 7.114E-03 4.627E-02 4.240E-02 4.864E-02 1.684E-02 1.877E-02 1.621E-02 1.372E-02 0.000E+00 0.000E+00 0.000E+00 0.000E+00  
 DEGRAD MOIS 6.247E-03 1.879E-02 1.514E-02 1.157E-02 9.035E-03 7.339E-03 6.031E-03 5.429E-03 5.007E-03 4.361E-03  
 DEGRAD SOIL 1.612E-05 4.559E-05 3.920E-05 3.195E-05 2.806E-05 2.405E-05 2.128E-05 1.893E-05 1.720E-05 1.548E-05 1.379E-05 1.243E-05  
 IN SOIL MOI 1.035E-01 9.436E-02 8.330E-02 7.454E-02 5.821E-02 5.246E-02 4.519E-02 3.710E-02 3.079E-02 2.771E-02 2.548E-02 2.226E-02  
 ADS ON SOIL 5.339E-04 4.578E-04 3.924E-04 3.147E-04 2.824E-04 2.402E-04 2.129E-04 1.914E-04 1.756E-04 1.580E-04 1.404E-04 1.269E-04  
 IN SOIL AIR 3.441E-01 2.948E-01 2.530E-01 2.067E-01 1.875E-01 1.588E-01 1.371E-01 1.236E-01 1.137E-01 1.022E-01 9.057E-02 8.208E-02  
 GWR. RUNOFF 9.852E+00 3.372E+01 3.136E+01 3.666E+01 1.978E+01 2.077E+01 1.703E+01 1.129E+01 7.406E+00 6.667E+00 6.702E+00 5.355E+00

MAXIMUM MASS/CONCENTRATION OF BENZENE IN LEACHATE AT POINT  
 LEACHATE PASSES INTO GROUNDWATER.

[33.72ug benzene in 6,707ml of recharge water = 0.005ug/ml  
 (i.e. Model is calibrated to meet drinking water-source objectives.)]

... POLLUTANT CONCENTRATIONS (UG/ML) OR (UG/G) ... NOTE: IF CONCENTRATIONS ARE ZERO FOR EACH MONTH, THEY ARE NOT PRINTED ...

UPPER SOIL ZONE: SUBLAYER 1  
 MOISTURE 8.724E-04 7.360E-04 6.184E-04 4.890E-04 4.321E-04 3.644E-04 3.158E-04 2.834E-04 2.597E-04 2.352E-04 2.101E-04 1.905E-04  
 %SOLUBILITY 4.847E-05 4.089E-05 3.435E-05 2.717E-05 2.401E-05 2.024E-05 1.754E-05 1.574E-05 1.443E-05 1.307E-05 1.167E-05 1.058E-05  
 ADSORBED 5.671E-05 4.784E-05 4.019E-05 3.179E-05 2.809E-05 2.369E-05 2.053E-05 1.842E-05 1.688E-05 1.529E-05 1.366E-05 1.238E-05  
 SOIL AIR 1.950E-04 1.651E-04 1.392E-04 1.131E-04 9.994E-05 8.427E-05 7.098E-05 6.346E-05 5.796E-05 5.241E-05 4.682E-05 4.244E-05

SOIL ZONE 2: SUBLAYER 1  
 MOISTURE 1.340E-03 1.145E-03 9.700E-04 7.765E-04 6.814E-04 5.776E-04 5.029E-04 4.492E-04 4.099E-04 3.706E-04 3.311E-04 2.995E-04  
 %SOLUBILITY 7.446E-05 6.361E-05 5.389E-05 4.314E-05 3.786E-05 3.209E-05 2.794E-05 2.496E-05 2.277E-05 2.059E-05 1.839E-05 1.664E-05  
 ADSORBED 8.712E-05 7.443E-05 6.305E-05 5.047E-05 4.429E-05 3.754E-05 3.269E-05 2.920E-05 2.665E-05 2.409E-05 2.152E-05 1.947E-05  
 SOIL AIR 2.996E-04 2.568E-04 2.183E-04 1.796E-04 1.576E-04 1.336E-04 1.130E-04 1.006E-04 9.149E-05 8.259E-05 7.378E-05 6.674E-05

SOIL ZONE 3: SUBLAYER 1  
 MOISTURE 5.476E-03 4.695E-03 4.025E-03 3.227E-03 2.897E-03 2.463E-03 2.184E-03 1.964E-03 1.801E-03 1.621E-03 1.440E-03 1.302E-03  
 %SOLUBILITY 3.042E-04 2.609E-04 2.236E-04 1.793E-04 1.609E-04 1.369E-04 1.213E-04 1.091E-04 1.000E-04 9.006E-05 7.999E-05 7.233E-05  
 ADSORBED 3.559E-07 3.052E-07 2.616E-07 2.098E-07 1.883E-07 1.601E-07 1.419E-07 1.276E-07 1.171E-07 1.054E-07 9.359E-08 8.463E-08  
 SOIL AIR 1.224E-03 1.053E-03 9.059E-04 7.464E-04 6.699E-04 5.697E-04 4.908E-04 4.398E-04 4.019E-04 3.612E-04 3.208E-04 2.901E-04

LOWER SOIL ZONE: SUBLAYER 1  
 MOISTURE 5.476E-03 4.695E-03 4.025E-03 3.227E-03 2.897E-03 2.463E-03 2.184E-03 1.964E-03 1.801E-03 1.621E-03 1.440E-03 1.302E-03  
 %SOLUBILITY 3.042E-04 2.609E-04 2.236E-04 1.793E-04 1.609E-04 1.369E-04 1.213E-04 1.091E-04 1.000E-04 9.006E-05 7.999E-05 7.233E-05  
 ADSORBED 3.559E-07 3.052E-07 2.616E-07 2.098E-07 1.883E-07 1.601E-07 1.419E-07 1.276E-07 1.171E-07 1.054E-07 9.359E-08 8.463E-08  
 SOIL AIR 1.224E-03 1.053E-03 9.059E-04 7.464E-04 6.699E-04 5.697E-04 4.908E-04 4.398E-04 4.019E-04 3.612E-04 3.208E-04 2.901E-04  
 POL DEP CM 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03 1.201E+03

TIME 2 (3<sup>rd</sup> year, 2<sup>nd</sup> month)

Leachate impacts groundwater at maximum benzene concentration.  
 (Initial groundwater impact - 3<sup>rd</sup> year, 1<sup>st</sup> month.)

YEAR - 3 ANNUAL SUMMARY REPORT

-- TOTAL INPUTS (UG) --

UPPER SOIL ZONE	0.000E+00
SOIL ZONE 2	0.000E+00
SOIL ZONE 3	0.000E+00
LOWER SOIL ZONE	0.000E+00

-- HYDROLOGIC CYCLE COMPONENTS --

AVERAGE SOIL MOISTURE ZONE 1 (%)	1.940
AVERAGE SOIL MOISTURE BELOW ZONE 1 (%)	1.940
TOTAL PRECIPITATION (CM)	153.470
TOTAL INFILTRATION (CM)	153.470
TOTAL EVAPOTRANSPIRATION (CM)	80.560
TOTAL SURFACE RUNOFF (CM)	0.000
TOTAL GRW RUNOFF (CM)	72.910
TOTAL MOISTURE RETENTION (CM)	0.000
TOTAL YIELD (CM)	72.910

-- POLLUTANT MASS DISTRIBUTION IN COLUMN (UG) --

NOTE: IF COMPONENT IS ZERO EACH MONTH, IT IS NOT PRINTED

FOR FINAL MASS IN SOIL MOI., ADS. ON SOIL, SOIL AIR, IMMOBIL CEC, COMPLEXED, AND PURE PHASE FOR EACH  
SUBLAYER, SEE ABOVE (MONTH SEP)

UPPER SOIL ZONE: SUBLAYER 1

TOTAL VOLATILIZED	4.442E+01
TOTAL DEGRADED (MOISTURE)	3.977E+00
TOTAL DEGRADED (SOIL)	9.781E+00

SOIL ZONE 2: SUBLAYER 1

TOTAL DIFFUSED (UP)	5.002E+01
TOTAL DEGRADED (MOISTURE)	3.109E+00
TOTAL DEGRADED (SOIL)	7.644E+00

SOIL ZONE 3: SUBLAYER 1

TOTAL DIFFUSED (UP)	4.916E+01
TOTAL DEGRADED (MOISTURE)	1.170E+02
TOTAL DEGRADED (SOIL)	2.879E-01

LOWER SOIL ZONE: SUBLAYER 1

TOTAL DIFFUSED (UP)	2.100E-01
TOTAL DEGRADED (MOISTURE)	1.161E-01
TOTAL DEGRADED (SOIL)	2.841E-04
TOTAL IN GROUNDWATER RUNOFF	2.066E+02

-- AVERAGE POLLUTANT CONCENTRATIONS --

NOTE: ONLY NON-ZERO VALUES ARE PRINTED --

UPPER SOIL ZONE: SUBLAYER 1

SOIL MOISTURE (UG/ML)	4.173E-04
ADSORBED SOIL (UG/G)	2.712E-05
SOIL AIR (UG/ML)	9.422E-05

SOIL ZONE 2: SUBLAYER 1

SOIL MOISTURE (UG/ML)	6.545E-04
ADSORBED SOIL (UG/G)	4.254E-05
SOIL AIR (UG/ML)	1.478E-04

SOIL ZONE 3: SUBLAYER 1

SOIL MOISTURE (UG/ML)	2.758E-03
ADSORBED SOIL (UG/G)	1.793E-07
SOIL AIR (UG/ML)	6.228E-04

LOWER SOIL ZONE: SUBLAYER 1

SOIL MOISTURE (UG/ML)	2.758E-03
ADSORBED SOIL (UG/G)	1.793E-07
SOIL AIR (UG/ML)	6.228E-04

MAX. POLL. DEPTH (M)	1.201E+01
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\*\*\*\*\*EXECUTION COMPLETED\*\*\*\*\*

**ATTACHMENT D2**  
**SESOIL MODEL WORKSHEET**

**SESOIL MODEL WORKSHEET**  
(submit for each SESOIL model)

Site Name: \_\_\_\_\_ DOH ID No. \_\_\_\_\_  
Site Address: \_\_\_\_\_

Model Run By: \_\_\_\_\_ Address: \_\_\_\_\_  
Signature: \_\_\_\_\_ Date: \_\_\_\_\_

Supporting Documents: (note report title, date, and preparer's name and address):

<b>MODULE 1: CLIMATE DATA</b>
Description of Run:
Raingage Station Name:
Number of years of climate data:
Number of years of simulation:

<b>MODULE 2: STATISTICAL CLIMATE DATA</b>									
Month	<sup>1</sup> Air Temperature (°C)	Cloud Cover	Humidity	Albedo	<sup>2</sup> Evapotranspiration (cm/day)	<sup>3</sup> Precipitation (cm/month)	Duration (days)	Number of Storms	Month Length (days)
Oct.									
Nov.									
Dec.									
Jan.									
Feb.									
Mar.									
Apr.									
May									
June									
July									
Aug.									
Sept.									
Annual Totals:      Precipitation (cm): Evapotranspiration (cm): Surface Runoff (cm): Groundwater Recharge (cm):  Source of input climate data (note if default data used):									

<b>MODULE 3: SOIL PROPERTIES</b>
Soil name:
Bulk density (g/cm <sup>3</sup> ):
Intrinsic permeability (cm <sup>2</sup> ):
Disconnectedness index:
Effective porosity:
Organic carbon content (%):
Cation exchange capacity (meq/100g):
Freundlich equation exponent:

<b>MODULE 4: CHEMICAL PROPERTIES</b>
Chemical name:
Solubility (mg/l):
Diffusion coefficient in air (cm <sup>2</sup> /sec):
Henry's Constant (m <sup>3</sup> -atm/mole):
Adsorption coeff. of organic carbon (ug/g-OC)/(ug/ml):
Adsorption coeff. (ug/g)/(mg/ml):
Molecular weight (g/mole):
Valence:
<b>CONSTANT</b>
Neutral hydrolysis (1/day):
Base hydrolysis (1/day):
Acid hydrolysis (1/day):
<b>BIODEGRADATION RATE</b>
Liquid phase (1/day):
Solid phase (1/day):
<b>COMPLEXATION</b>
Ligand stability constant:
Moles ligand per mole:
Molecular weight of ligand (g/mole):

<b>MODULE 5: APPLICATION AND WASHLOAD DATA</b>
<b>WASHLOAD SIMULATION:</b> used/not used (circle one)
<b>APPLICATION DATA</b>
Number of (simulation/application) years:
Number of soil layers:
Application area (cm <sup>2</sup> ):
Latitude of site (deg. N):
<b>SPILL (SIMULATION MODE)</b>
instantaneous/continuous (circle one)
<b>POLLUTANT LOAD (MODE)</b>
mass per unit area/concentration (circle one)
<b>WASHLOAD</b>
Number of years of data:
Washload area (cm <sup>2</sup> ):
Silt:
Sand:
Clay:
Slope length (cm):
Average slope (cm/cm):

<b>MODULE 6: SOIL COLUMN PROPERTIES</b>						
	Layer 1	Layer 2	Layer 3			
Thickness (cm)						
Number of Sublayers						
PH						
Intrinsic Permeability (cm <sup>2</sup> )						
Liquid Biodegradation						
Solid Biodegradation						
OC Content						
Cation Exchange						
Ratio Freundlich						
Ratio Absorption						

<b>MODULE 7: POLLUTANT LOADING FOR IMPACTED LAYER(s)</b>
Model layer number:
Load (ug/cm <sup>2</sup> ):
Concentration:
Mass Transformed (ug/cm <sup>2</sup> ):
Sink (ug/cm <sup>2</sup> ):
Ligand (ug/cm <sup>2</sup> ):
Volatilization:
Runoff Index:
Ratio:

<b>SESOIL MODEL SIMULATION RESULTS</b>
<sup>1</sup> Depth to groundwater (m):
Thickness of impacted layer (cm):
<sup>2</sup> Areal extent of impacted layer (cm <sup>2</sup> ):
<sup>3</sup> Target leachate concentration at groundwater impact (mg/l):
Time of maximum impact on groundwater (yr/mo):
Volume of recharge water for that month (liters):
Target maximum groundwater contaminant runoff mass for month (mg):
Calibrated input soil concentration (ug/g):
Actual maximum groundwater contaminant runoff mass for month (mg):
<sup>4</sup> Actual leachate concentration at groundwater impact (mg/l):
Time dissolved plume passes through base of impacted layer (yr/mo):
Mass of contaminant in impacted layer at that time (ug):
Mass of impacted layer (g):
Concentration of contaminant in impacted layer at that time (ug/g):
<b>FINAL RESULTS:</b>
Contaminant:
SESOIL-generated soil action level (mg/kg):

Notes:

1. Depth to groundwater from base of impacted layer.
2. Equals application area in Module 5.
3. Groundwater action level for site (not including dilution).
4. Model-derived concentration of contaminant in leachate at the point the leachate passes into groundwater.



## **APPENDIX E**

### **MODIFICATION AND USE OF USEPA REGION IX DIRECT-EXPOSURE MODELS**

## MODIFICATION AND USE OF USEPA REGION IX DIRECT-EXPOSURE MODELS

### INTRODUCTION

Quantitative, risk-based, deterministic models used by EPA Region IX for development of "Preliminary Remediation Goals (PRGs)" are used by DOH to generate direct-exposure soil action levels for Tier 1 and Tier 2 purposes. A list of direct-exposure action levels for common contaminants is presented in Appendix F. The action levels generated are intended to ensure that the excess cancer risks resulting from residential exposure to impacted soils left in place at a release site do not exceed one-in-a-million ( $10^{-6}$ ) and that the hazard quotient for non-carcinogenic contaminants does not exceed a value of "one."

Use of the models to evaluate direct-exposure concerns on a more site-specific basis is referred to as "Tier 2." Guidelines for the generation and presentation of Tier 2 soil action levels are provided in Chapter 2.

### GENERATION OF DIRECT-EXPOSURE SOIL ACTION LEVELS

#### Model Equations

Slightly modified versions of equations presented in the First Half, 1995, edition of EPA Region IX's PRG document (USEPA, 1995) are used to generate Tier 1 direct-exposure soil action levels. A description of the models is provided in Attachment 1. Equations used in the models reflect guidance provided in the California EPA document entitled "Preliminary Endangerment Guidance Manual, January, 1994." A copy of this document is available from the DOH Solid and Hazardous Waste Branch.

Risk (R) to human health posed by soils impacted with carcinogenic contaminants is calculated by solving equation 4-1 for R. The hazard quotient (HQ) for non-carcinogenic contaminants is similarly calculated by solving equation 4-2 for HQ. Note that the volatilization factor term in the direct-exposure models is replaced with the particulate emission factor term for non-volatile contaminants (defined as having a Henry's Law Constant ( $\text{atm}\cdot\text{m}^3/\text{mol}$ ) less than or equal to  $10^{-5}$  and a molecular weight less than 200 grams/mol).

In equations 4-9 and 4-11, the air dispersion term incorporated into the volatilization and particulate emission factors is modified to allow input of site-specific data. This reflects guidance presented in earlier editions of the PRGs. Refer to the discussion at the beginning of Attachment 1 for details on this modification. In addition, a "mass-balanced" term is incorporated into the volatilization factor model to take into account the actual thickness of impacted soil at a site (refer to Attachment 1). (Note that the thickness of the impacted soil is not considered in either equation 4-9 or 4-11.) Tier 1 SALs assume a default thickness of impacted soil of two meters.

## **Default Exposure Assumptions**

The Tier 1, direct-exposure soil action levels presented conservatively assume exposure to a contaminant by inhalation, ingestion, and dermal absorption in a residential setting. Default exposure parameter values are noted in Table 1.

## **Input Physio-chemical and Toxicity Data**

Published physio-chemical constants for some contaminants can vary widely from source to source. For consistency between sites, physio-chemical constants provided in the EPA Region IX PRGs are used in the models (Table 2). Toxicity constants used in the models (Table 3) are taken from the EPA PRG reports. The toxicity constants used in the PRGs are consistent with the EPA "IRIS" and "HEAST" data bases (USEPA, 1994b; USEPA, 1994c).

## **Input Site data**

Table 4 denotes the site characteristic parameters that were used in the direct-exposure models. With the exception of windspeed, the optional, default parameter values presented in Table 4 reflect those used in the PRGs. The default windspeed given reflects one-half the 11mph average windspeed reported for the Honolulu airport between 1985 and 1993 (USDOC, 1985-1993).

## **USE OF TIER 1 DIRECT-EXPOSURE SOIL ACTION LEVELS**

The direct-exposure models presented do not take into account potential groundwater impact from contaminants leaching out of vadose zone media nor do they address potential indoor air concerns for sites where contaminated soil is situated directly beneath buildings. At a large percentage of contaminant release sites, however, buildings are not located over impacted soil and groundwater is already known to have been impacted.

Where groundwater has already been impacted, it may be more appropriate to evaluate leachate concerns by on-site groundwater monitoring (refer to guidance presented in the main document). If so, and groundwater at an impacted site is not being impacted above DOH-recommended criteria then soil remedial efforts need only to address direct-exposure concerns. Note also that the contribution of re-mobilized, dissolved-phase volatile contaminants in groundwater to surface air emissions is generally shown by theoretical models to be minimal and evaluation of this exposure pathway is not required at LUST facilities unless otherwise directed by DOH.

TABLE 1. Exposure parameters and default values used in Tier 1 direct-exposure models.

<b>Human Receptor Data</b>	<b>Default</b>
25% surface area - adults (cm <sup>2</sup> )	5000
25% surface area - children (cm <sup>2</sup> )	2000
Adherence factor (unitless)	0.2
Inhalation Rate - adults (m <sup>3</sup> /d)	20
Inhalation Rate - children (m <sup>3</sup> /d)	10
Soil ingestion rate - adults (mg/d)	100
Soil ingestion rate - children (mg/d)	200
Exposure time - residents (h/d)	24
Exposure frequency - residents (d/y)	350
Exposure duration - residents total (yrs)	30
Exposure duration - children (yrs)	6
Body weight - adult (kg)	70
Body weight - child (kg)	15
Averaging time (yrs)	70
<b>Other variables</b>	
Diffusion height (m)	2

TABLE 2. Physio-chemical constants used in Tier 1 direct-exposure models.

<sup>1</sup> Constituent	Water Solubility (mg/l)	Diffusion Coefficient-air (cm <sup>2</sup> /s)	Henry's Constant (m <sup>3</sup> -atm/mole)	KOC (ml/g)	Molecular Weight
Benzene	1800	0.088	0.0055	65	78
Toluene	520	0.078	0.0066	260	92
Ethylbenzene	680	0.075	0.0079	220	110
Xylene (mixed)	200	0.087	0.0053	240	110
<sup>2</sup> Benzo(a)pyrene	0.0039	0.045	0.0000024	881000	252
Acenaphthene	4	0.064	0.0012	4600	150
<sup>2</sup> Fluoranthene	0.26	0.051	0.0000087	41700	202
Naphthalene	31	0.069	0.0013	1300	130
PCE	150	0.072	0.023	660	170
1,1 DCE	400	0.079	0.15	65	97
Vinyl Chloride	1100	0.110	0.70	57	63
TCE	1000	0.081	0.0089	130	130
1,1,1 TCA	950	0.080	0.0028	150	130

1. Source of data USEPA (1995) unless otherwise noted.
2. Data after Montgomery and Welkom (1991) and Neff et al. (1994).

TABLE 3. Toxicity data used in Tier 1 direct-exposure models.

Contaminant	Cancer Slope Factor (oral) [1/(mg/kg-d)]	Cancer Slope Factor (inhalation) [1/(mg/kg-d)]	Reference Dose (oral) [mg/kg-d]	Reference Dose (inhalation) [mg/kg-d]
Benzene	2.90E-02	2.90E-02		
Toluene			2.00E-01	1.10E-01
Ethylbenzene			1.00E-01	2.90E-01
Xylene			2.00E+00	2.00E-01
Benzo(a)pyrene	7.30E+00	7.30E+00		
Acenaphthene			6.00E-02	6.00E-02
Fluoranthene			4.00E-02	4.00E-02
Naphthalene			4.00E-02	4.00E-02
PCE	5.20E-02	2.00E-02	1.00E-02	1.00E-02
1,1 DCE	6.00E-01	1.80E-01	9.00E-03	9.00E-03
Vinyl Chloride	1.90E+00	3.00E-01		
TCE	1.1E-02	6.0E-03	6.0E-03	6.0E-03
1,1,1 TCA			9.0E-02	2.9E-01

TABLE 4. Site characteristic parameters and default values used in Tier 1 direct-exposure models.

	<sup>1</sup> <u>Default Values</u>
Areal extent of contamination (meters <sup>2</sup> )	2025m <sup>2</sup>
Soil density (grams/meter <sup>3</sup> )	1.50g/m <sup>3</sup>
Particle density (grams/meter <sup>3</sup> )	2.65g/m <sup>3</sup>
Soil porosity (total)	43%
Soil air-filled porosity	28%
Soil moisture content (milliliters water/grams soil)	10ml/g
Fraction organic carbon	0.02
Average wind speed (meters/second)	2.5m/s (5mph)

1. Same as used for EPA Region IX Preliminary Remediation Goals (USEPA, 1995).

**ATTACHMENT E1**

**MODIFICATION OF USEPA REGION IX  
DIRECT-EXPOSURE MODELS**



## MODIFICATION OF FIRST-HALF, 1995, PRG EQUATIONS

### Modification of VF and PEF factors to Include Site-Specific Air Dispersion Term

The air dispersion and emission rate terms used in the Second Half, 1994, PRG report were taken from the California "Preliminary Endangerment Guidance Manual, January, 1994" (Fig. 2-27 and page B-1, CAEPA, 1994). In contrast, the First Half, 1995, version of the PRGs incorporates default air dispersion values (Q/C term) into the VF and PEF equations rather than using an algorithm that reflects site-specific parameters as was done in 1994 version of the PRGs.

**For Tier 1 and 2 purposes, the Q/C term in the 1995 PRG volatilization factor and particulate emission factor equations is replaced with the original air dispersion term** that takes into account the length of the side of the contaminated site perpendicular to the wind direction (LS, in meters), the average wind velocity (V, in meters/second), and the assumed diffusion height (DH, default value = 2 meters):

$$Q/C = (LS \times V \times DH)/\text{area}$$

The spreadsheet model assumes that the impacted area is square in shape (i.e.,  $LS = \text{area}^{0.5}$ ). Note that this air dispersion factor term is also used in the ASTM document "Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (July, 1994)." (The ASTM version is presented in simplified form:  $LS \times V \times DH/\text{Area}$  as used in the PRG/California models equals  $U_{\text{air}}\delta_{\text{air}}/W$  as used in ASTM's Table X2.1, where  $U_{\text{air}}$  = wind speed,  $\delta_{\text{air}}$  = ambient air mixing/diffusion zone height, and  $W$  = length of the side of the contaminated site parallel to the wind direction. Note that ASTM also uses a default air mixing height of 2 meters.)

### Modification of Volatilization Factor to Reflect Volume of Impacted Soil

Note that a soil thickness term is not included in the modified Volatilization Factor or Particulate Emissions Factor equations described above. For non-volatile contaminants this assumption is inconsequential to the results of the direct-exposure models. For volatile contaminants, however, the actual volume of impacted soil, or rather the actual mass of contaminant in the impacted soil at a site is especially important.

At sites with small volumes of impacted soil, the actual mass of contaminant at the site may not be adequate to sustain the theoretically calculated volatile emission rate (from equation 4-9) over the entire exposure duration period specified in the model. In these cases, it is more appropriate to incorporate a conservative "mass-balanced" model of volatile emissions into the direct exposure assessment, where the maximum volatile emission rate is calculated by dividing the estimated mass of contaminant at the site by the desired exposure duration period. The corresponding, "mass-balanced" volatilization factor equation is derived below.

Total mass (in grams) of contaminant at a release site is estimated by calculating the

volume of impacted soil (area x thickness), converting soil volume to soil mass (volume x soil density), and then multiplying the mass of impacted soil (in Kg) by a conservative estimate of the concentration of the contaminant in the soil (e.g., 95% upper confidence limit of the arithmetic mean concentration, in grams/kg):

contaminant mass = soil mass x contaminant concentration.

A worst-case exposure scenario would be for all of the volatile contaminant to be emitted from the soil during the specified exposure duration period (e.g. 30 years). The corresponding "mass-balanced" emission rate ( $Ei_{mb}$ ) of the contaminant from the soil would simply be the total mass of the contaminant divided by the model exposure duration (in seconds):

$Ei_{mb}$  = contaminant mass/exposure duration.

This mass-balanced emission rate for the site represents the maximum volatile emission rate that could possibly occur at the site as averaged over the specified exposure duration.

**The mass-balanced emission rate should be substituted into the Volatilization Factor equation when it is less than the calculated theoretical emission rate** (i.e., when the theoretical calculation over estimates the maximum possible emission rate from the site averaged over the specified exposure duration). In these cases, the volatilization factor will be calculated simply as:

$$VF = (LS \times V \times DH)/(Ei_{mb}/C_s)$$

where  $C_s$  is again the model concentration of the contaminant in the impacted soil.

In the DETIER2 and DETIER3 spreadsheets, both a theoretical, volatile emission rate and a mass-balanced emission rate are calculated based on the input site data. The spreadsheet then compares the results of the calculations and chooses the appropriate (lowest) emission rate term for incorporation into the volatilization factor. A message will appear beside the model results on the spreadsheet that denotes whether the theoretical (PRG) or mass-balanced equation was chosen for use in the model. Note that the mass-balanced volatilization factor will be used for most small sites impacted with volatile contaminants. If the contaminant is non-volatile, a message will appear that the particulate-emission equation was used. The spreadsheet was used to generate direct-exposure SALs for the Tier 1 lookup table with a default assumption the contaminated soil was two meters thick.

In the DETIER2 and DETIER3 spreadsheets, both a theoretical, volatile emission rate and a mass-balanced emission rate are calculated based on the input site data. The spreadsheet then compares the results of the calculations and chooses the appropriate (lowest) emission rate term for incorporation into the volatilization factor. A message will appear beside the model results on the spreadsheet that denotes whether the theoretical (PRG) or mass-balanced equation was chosen for use in the model. Note that the mass-balanced volatilization factor will be used for most small sites impacted with volatile contaminants. If the contaminant is non-volatile, a message will appear that the particulate-emission equation was used. The spreadsheet was used to generate direct-exposure SALs for the Tier 1 lookup table with a default assumption the contaminated soil was two meters thick.



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IX

75 Hawthorne Street  
San Francisco, CA 94105-3901

February 1, 1995

Subject: Region IX Preliminary Remediation Goals (PRGs) First Half 1995

From: Stanford J. Smucker, Ph.D.  
Regional Toxicologist (H-9-3)  
Technical Support Section

To: PRG Table Mailing List

Please find the update to the Region IX PRG table. The table has been revised to reflect the most current EPA toxicological and risk assessment information. Updates to EPA toxicity values were obtained from IRIS through December 1994 and HEAST through November 1994.

Preliminary Remediation Goals are "evergreen" and will change as new methodologies and parameters are developed. Notable changes in this version of the update include the methods for relating contaminant concentrations in soil to contaminant concentrations in the breathing zone. The dispersion term for the inhalation of volatiles and fugitive dusts emitted from contaminated soils is modeled using an updated dispersion model (AREA-ST, the updated version of the Office of Air Quality Planning and Standards, Industrial Source Complex Model, ISC2). This leads to small changes in the volatilization factors (VF<sub>s</sub>) and PEF, and consequently, small changes in the estimate of soil PRGs for volatile contaminants.

The PRG table provides useful risk-based information for Region IX risk assessors and managers. It is noted that California risk-based PRGs ("CAL-Modified PRGs") may differ significantly from the federal values (significance is defined here as differing by a factor of four or more). Where "CAL-Modified PRGs" are significantly more restrictive than the federal numbers, they are also presented in the tables and should be used within the State of California.

In general, PRGs should be used as a predictor of single-contaminant risk estimates for a specific environmental media (e.g. soil, air, and tap water). However, multiple contaminant risks can also be estimated by summing the fractional contribution of each contaminant (see Screening Risk below). This procedure requires gathering additional information, either by downloading the table to display the hidden columns or by using the equations presented in the text for calculating additional concentration terms not provided in the print out.

A contaminant concentration that exceeds a PRG level does not, in itself, mean that there is an unacceptable health threat. However, exceedances should be evaluated further. It is recommended that the reader verify the numbers with a toxicologist because the toxicity/exposure information in the table may contain errors or default assumptions that need to be refined based on further evaluation.

If you are not currently on the PRG mailing list, but would like to be, please make the request through EPA's project manager working on your site. Or, simply download the file (PRG1ST95.ZIP) from California Regional Water Board's BBS [(510) 286-0404]. If you find an error please send me a note via fax at (415) 744-1916.

## DISCLAIMER

Preliminary remediation goals (PRGs) focus on common exposure pathways and may not consider all exposure pathways encountered at CERCLA/RCRA sites (Exhibit 1-1). PRGs do not consider impact to groundwater or address ecological concerns. PRGs are specifically not intended as a (1) stand-alone decision-making tool, (2) as a substitute for EPA guidance for preparing baseline risk assessments, or (3) a rule to determine if a waste is hazardous under RCRA.

The guidance set out in this document is not final Agency action. It is not intended, nor can it be relied upon to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided herein, or act at variance with the guidance, based on an analysis of specific circumstances. The Agency also reserves the right to change this guidance at any time without public notice.

## 1.0 INTRODUCTION

The Region IX PRG Table combines EPA toxicity values (updated biannually) with reasonable maximum exposure (RME) factors to estimate concentrations in environmental media (e.g. soil, air, and water) that are protective of humans, including sensitive groups, over a lifetime of exposure. Concentrations above these levels would not automatically designate a site as "dirty" or trigger a response action. However, exceeding a PRG suggests that further evaluation of the potential risks that may be posed by site contaminants is appropriate. PRGs are "evergreen" and will change as new methodologies and parameters are developed.

PRG concentrations presented in the Tables can be used to screen pollutants in environmental media, trigger further investigation, and provide an initial cleanup goal if applicable. When considering PRGs as initial cleanup goals, residential concentrations should be used for maximum beneficial uses of a property. Industrial concentrations for soil only are included in the table as an alternative goal, but industrial concentrations should not be used for screening a site. They are meant to provide the manager with an alternative preliminary goal for sites zoned industrial.

Before applying PRGs as screening tools or initial cleanup goals, the user of the table should consider whether the exposure pathways and exposure scenarios at the site are fully accounted for in the PRG calculation. Region IX PRG concentrations are based on exposure pathways for which generally accepted methods, models, and assumptions have been developed (i.e. ingestion, dermal contact, and inhalation) for specific land-use conditions and do not consider impact to groundwater or ecological receptors (see Developing a Conceptual Site Model below).

EXHIBIT 1-1  
TYPICAL EXPOSURE PATHWAYS BY MEDIUM  
FOR RESIDENTIAL AND INDUSTRIAL LAND USES\*

EXPOSURE PATHWAYS, ASSUMING:		
MEDIUM	RESIDENTIAL LAND USE	INDUSTRIAL LAND USE
Ground Water	<i>Ingestion from drinking</i>	Ingestion from drinking
	<i>Inhalation of volatiles</i>	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
Surface Water	<i>Ingestion from drinking</i>	Ingestion from drinking
	<i>Inhalation of volatiles</i>	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
	Ingestion during swimming	
	Ingestion of contaminated fish	
Soil	<i>Ingestion</i>	<i>Ingestion</i>
	<i>Inhalation of particulates</i>	<i>Inhalation of particulates</i>
	<i>Inhalation of volatiles</i>	<i>Inhalation of volatiles</i>
	Exposure to indoor air from soil gas	Exposure to indoor air from soil gas
	Exposure to ground water contaminated by soil leachate	Exposure to ground water contaminated by soil leachate
	Ingestion via plant uptake	Inhalation of particulates from trucks and heavy equipment
	<i>Dermal absorption</i>	<i>Dermal absorption</i>

Footnote:

\*Exposure pathways considered in the PRG calculations are indicated in boldface italics.

## 2.0 READING THE PRG TABLE

### 2.1 General Considerations:

With the exceptions described below, PRGs are health-based concentrations that correspond to either a one-in-one million ( $10^{-6}$ ) cancer risk or a chronic hazard quotient of one, whichever is lower. PRG concentrations based on cancer and noncancer concerns are indicated by "ca" and "nc", respectively. Cancer-causing agents may have additional non-cancer PRGs not listed in the Tables. These can be obtained by downloading file (PRG1ST95.ZIP) from California Regional Water Board's Bulletin Board System at [(510)286-0404] or using the calculations provided below.

In general, PRG concentrations in the table are risk-based but for soil there are two important exceptions: 1) for several volatile chemicals PRGs are based on soil saturation equation ("sat") (see below), and 2) for relatively less toxic inorganic and semivolatile contaminants, a non-risk based "ceiling limit" concentration is given as  $10^{-5}$  mg/kg "max". PRG concentrations that are not risk-based (i.e. either "sat" or "max") should be segregated before screening multiple pollutant risks.

### 2.2 Toxicity Values:

EPA toxicity values, known as noncarcinogenic reference doses (RfD) and carcinogenic slope factors (SF) were obtained from IRIS through December 1994, HEAST through November 1994, and ECAO-Cincinnati. The priority among sources of toxicological constants used are as follows: (1) IRIS (indicated by "i"), (2) HEAST ("h"), (3) ECAO ("e"), and (4) withdrawn from IRIS or HEAST and under review ("x").

Route-to-route extrapolations ("r") were frequently used when there were no toxicity values available for a given route of exposure. Oral cancer slope factors ("oSF") and reference doses ("oRfD") were used for both oral and inhaled exposures for organic compounds lacking inhalation values. Also, inhalation slope factors ("iSF") and inhalation reference doses ("iRfD") were frequently used for both inhaled and oral exposures for organic compounds lacking oral values. An additional route extrapolation is the use of oral toxicity values for evaluating dermal exposures. Although route-to-route methods are a useful screening procedure, the appropriateness of these default assumptions for specific contaminants should be verified by a toxicologist.

### 2.3 Soil Factors:

Chemical-specific information for soils, volatilization factors ("VF<sub>s</sub>") and skin absorption factors ("ABS"), are listed in the table to provide additional assumptions used to calculate soil PRGs. For volatile chemicals, the "VF<sub>s</sub>" term was incorporated into the PRG equations to address long-term inhalation exposures. Volatile organic chemicals (VOCs) are indicated by "1" in the VOC column of the Table and are defined as those chemicals having a Henry's Law constant greater than  $10^{-5}$  (atm-m<sup>3</sup>/mol) and a molecular weight less than 200 g/mole).

Chemical-specific soil "ABS" values are provided for arsenic, cadmium, pentachlorophenol, PCBs, and dioxin as recommended by EPA's Office of Research and Development (1994) for the evaluation of contaminant absorption through the skin. Otherwise, default skin absorption fractions are assumed to be 0.01 and 0.10, for inorganics and organics, respectively. Although it is debatable whether a default of 0.10 skin absorption is appropriate for volatile contaminants in soils, it should be noted that in practical terms, this assumption makes little difference in the soil PRG because the risk driver for volatiles is generally based on the soil-to-air pathway and not ingestion or skin contact.

### 3.0 USING THE PRG TABLE

The decision to use PRGs at a site will be driven by the potential benefits of having risk-based concentrations in the absence of site-specific risk assessments. The original intended use of PRGs was to provide initial cleanup goals for individual chemicals given specific medium and land-use combinations (see RAGS Part B, 1991), however risk-based PRGs actually have several uses in addition to providing initial goals. These include:

- Screening sites to determine further evaluation
- Prioritizing areas of concern at megasites (e.g. federal facilities)
- Calculating risks associated with multiple contaminants

A few basic procedures are recommended for using PRGs properly. These are briefly described below. Potential problems with the use of PRGs are also identified.

#### 3.1 Developing a Conceptual Site Model

The primary condition for use of PRGs is that exposure pathways of concern and conditions at the site match those taken into account by the PRG framework. Thus, it is always necessary to develop a conceptual site model (CSM) to identify likely contaminant source areas, exposure pathways, and potential receptors. This information can be used to determine the applicability of PRGs at the site and the need for additional information. For those pathways not covered by PRGs, a risk assessment specific to these additional pathways may be necessary. Nonetheless, the PRG lookup values will still be useful in such situations for focusing further investigative efforts on the exposure pathways not addressed.

To develop a site-specific CSM, perform an extensive records search and compile existing data (e.g. available site sampling data, historical records, aerial photographs, and hydrogeologic information). Once this information is obtained, CSM worksheets such as those provided in ASTM's *Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* (1994) can be used to tailor the generic worksheet model to a site-specific CSM. The final CSM diagram represents linkages among contaminant sources, release mechanisms, exposure pathways and routes and receptors. It summarizes our understanding of the contamination problem.

As a final check, the CSM should answer the following questions:

- Are there potential ecological concerns?
- Is there potential for land use other than those covered by the PRGs (that is, residential and industrial)?
- Are there other likely human exposure pathways that were not considered in development of the PRGs (e.g. impact to groundwater, local fish consumption; raising beef, dairy, or other livestock)?
- Are there unusual site conditions (e.g. large areas of contamination, high fugitive dust levels, potential for indoor air contamination)?

If any of these four conditions exist, the PRG may need to be modified to reflect this new information. Suggested references for evaluating pathways not currently evaluated by Region IX PRG's are presented in Exhibit 3-1.



**EXHIBIT 3-1**  
**SUGGESTED READINGS FOR EVALUATING SOIL CONTAMINANT**  
**PATHWAYS NOT CURRENTLY ADDRESSED BY REGION IX PRGs**

EXPOSURE PATHWAY	REFERENCE
Migration of contaminants to an underlying potable aquifer	<i>Technical Background Document for Soil Screening Guidance - Review Draft (USEPA 1994c)</i>
Ingestion via plant uptake	<i>Technical Support Document for Land Application of Sewage Sludge (USEPA 1992a)</i>
Ingestion via meat or dairy products	<i>Estimating Exposure to Dioxin-Like Compounds - Review Draft (1994d)</i>
Inhalation of volatiles that have migrated into basements	<i>Technical Background Document for Soil Screening Guidance - Review Draft (USEPA 1994c)</i>
Terrestrial environmental pathways	<i>Role of the Ecological Risk Assessment in the Baseline Risk Assessment (USEPA 1994e)</i>

### 3.2 Background Levels Evaluation

A necessary step in determining the usefulness of Region IX PRGs is the consideration of background contaminant concentrations. EPA may be concerned with two types of background at sites: naturally occurring and anthropogenic. Natural background is usually limited to metals whereas anthropogenic (i.e. human-made) background includes both organic and inorganic contaminants.

Generally EPA does not clean up below natural background. If natural background concentrations are higher than the PRGs, the generic PRGs may not be the best tool for site decisionmaking. Or, an adjustment of the PRG may be needed. For example, naturally occurring arsenic frequently is higher than the soil PRG set equal to a one-in-one-million cancer risk (the point of departure), thus an alternative PRG for arsenic is provided in the lookup tables based on non-cancer endpoints. Because of the problems associated with adjusting PRGs to an alternate risk level, this procedure is not recommended without first consulting a staff toxicologist at state and/or federal regulatory agencies.

Where anthropogenic background levels exceed PRGs and EPA has determined that a response action is necessary and feasible, EPA's goal will be to develop a comprehensive response to the widespread contamination. This will often require coordination with different authorities that have jurisdiction over the sources of contamination in the area.

### 3.3 Risk Screening

A suggested stepwise approach for screening sites with PRGs is as follows:

- Perform an extensive records search and compile existing data
- Identify site contaminants in the PRG Table. Record the PRG concentrations for various media and note whether PRG is based on cancer risk (indicated by "ca") or

noncancer hazard (indicated by "nc"). Segregate cancer PRGs from non-cancer PRGs and exclude (but don't eliminate) non-risk based PRGs ("sat" or "max").

- For cancer risk estimates, take the site-specific concentration (maximum or 95 UCL) and divide by the PRG concentrations that are designated for cancer evaluation ("ca"). Multiply this ratio by  $10^{-6}$  to estimate chemical-specific risk. For multiple pollutants, simply add the risk for each chemical:

$$Risk = \left[ \left( \frac{conc_x}{PRG_x} \right) + \left( \frac{conc_y}{PRG_y} \right) + \left( \frac{conc_z}{PRG_z} \right) \right] \times 10^{-6}$$

- For non-cancer hazard estimates. Divide concentration term by its respective non-cancer PRG designated as "nc" and sum the ratios for multiple contaminants. [Note that carcinogens may also have an associated non-cancer PRG that is not listed in the printed copy of the table and these will also need to be obtained in order to complete the non-cancer evaluation.] The non-cancer ratio represents a hazard index (HI). A hazard index of 1 or less is generally considered safe. A ratio greater than 1 suggests further evaluation:

$$Hazard\ Index = \left[ \left( \frac{conc_x}{PRG_x} \right) + \left( \frac{conc_y}{PRG_y} \right) + \left( \frac{conc_z}{PRG_z} \right) \right]$$

For more information on screening site risks, the reader should contact EPA Region IX's Technical Support Section.

### 3.4 Potential Problems:

As with any risk-based tool, the potential exists for misapplication. In most cases the root cause will be a lack of understanding of the intended use of Region IX PRGs. In order to prevent misuse of PRGs, the following should be avoided:

- Applying PRGs to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios,
- Not considering background concentrations when choosing PRGs as cleanup goals,
- Use of PRGs as cleanup levels without the nine-criteria analysis specified in the National Contingency Plan (or, comparable analysis for programs outside of Superfund),
- Use of PRGs as cleanup levels without verifying numbers with a toxicologist,
- Use of antiquated PRG Tables that have been superseded by more recent publications, and
- Not considering the effects of additivity when screening multiple chemicals.

## 4.0 TECHNICAL SUPPORT DOCUMENTATION

PRGs consider human exposure hazards to chemicals from contact with contaminated soils, air, and water. The emphasis of the PRG equations and technical discussion are aimed at developing initial goals for soils; since this is an area where few standards exist. For air and water, additional reference concentrations or standards are available for many chemicals (e.g. non-zero MCLGs, AWQC, and NAAQS) and consequently the discussion of these media are brief.

### 4.1 Inhalation of Volatiles and Fugitive Dusts:

Agency toxicity criteria indicate that risks from exposure to some chemicals via inhalation far outweigh the risk via ingestion; therefore soil PRGs have been designed to address this pathway as well. The models used to calculate PRGs for inhalation of volatiles/particulates are updates of risk assessment methods presented in RAGS Part B (USEPA 1991a) and are consistent with the *Technical Background Document for Soil Screening Guidance - Review Draft* (USEPA 1994c).

To address the soil-to-air pathways the PRG calculations incorporate volatilization factors (VF<sub>s</sub>) for volatile contaminants and particulate emission factors (PEF) for nonvolatile contaminants. These factors relate soil contaminant concentrations to air contaminant concentrations that may be inhaled on-site. The VF<sub>s</sub> and PEF equations can be broken into two separate models: an emission model to estimate emissions of the contaminant from the soil and a dispersion model to simulate the dispersion of the contaminant in the atmosphere.

It should be noted that the box model in RAGS Part B has been replaced with a dispersion term (Q/C) derived from a modeling exercise using meteorological data from 29 locations across the United States because the box model may not be applicable to a broad range of site types and meteorology and does not utilize state-of-the-art techniques developed for regulatory dispersion modeling. The dispersion model for both volatiles and particulates is the AREA-ST, an updated version of the Office of Air Quality Planning and Standards, Industrial Source Complex Model, ISC2. However, different Q/C terms are used in the VF and PEF equations. Los Angeles was selected as the 90th percentile data set for volatiles and Minneapolis was selected as the 90th percentile data set for fugitive dusts (USEPA 1994c). A default source size of 0.5 acres was chosen for the PRG calculations. This differs from the default area source (30 acres) assumed in *Technical Background Document for Soil Screening Guidance - Review Draft* (USEPA 1994c). Based on communications with project managers and technical staff, an assumed source size of 30 acres was considered inappropriate for most sites. In addition, these air models are already biased towards predicting long-term exposure concentrations in excess of those likely to occur. If unusual site conditions exist such that the area source is substantially larger than the default source size assumed here, an alternative Q/C could be applied (see USEPA 1994c).

#### Volatilization Factor for Soils

Volatile chemicals, defined as those chemicals having a Henry's Law constant greater than  $10^{-5}$  (atm-m<sup>3</sup>/mol) and a molecular weight less than 200 g/mole, were screened for inhalation exposures using a volatilization factor for soils (VF<sub>s</sub>).

The emission terms used in the VF<sub>s</sub> are chemical-specific and were calculated from physical-chemical information obtained from a number of sources including *Superfund Exposure Assessment Manual* (reference "1")(SEAM, EPA 1988), *Superfund Public Health Evaluation Manual* (reference "2")(EPA 1986), *Subsurface Contamination Reference Guide* (reference "3")(EPA 1990a) and *Fate and Exposure*

Data (reference "4")(Howard 1991) and are presented in Attachment A. In those cases where Diffusivity Coefficients ( $D_i$ ) were not provided in existing literature,  $D_i$ 's were calculated using Fuller's Method described in SEAM. A surrogate term was required for some chemicals that lacked physico-chemical information. In these cases, a proxy chemical of similar structure was used that may over- or under-estimate the PRG for soils.

Equation 4-9 forms the basis for deriving generic soil PRGs for the inhalation pathway. The following parameters in the standardized equation can be replaced with specific site data to develop a more site-specific PRG

- Source area
- Average soil moisture content
- Average fraction organic carbon content
- Dry soil bulk density

The basic principle of the  $VF_s$  model is applicable only if the soil contaminant concentration is at or below soil saturation. Above this level the model cannot predict an accurate VF. If the PRG calculated using  $VF_s$  was greater than the calculated "sat", the PRG was set equal to "sat" in accordance with Risk Assessment Guidance for Superfund - Part B (EPA, 1991). Equation 4-10 forms the basis for deriving soil saturation concentrations.

#### Volatilization Factor for Tap Water

For tap water, an upperbound volatilization constant ( $VF_w$ ) is used that is based on all uses of household water (e.g. showering, laundering, and dish washing). Certain assumptions were made. For example, it is assumed that the volume of water used in a residence for a family of four is 720 L/day, the volume of the dwelling is 150,000 L and the air exchange rate is 0.25 air changes/hour (Andelman in RAGS Part B). Furthermore, it is assumed that the average transfer efficiency weighted by water use is 50 percent [i.e. half of the concentration of each chemical in water will be transferred into air by all water uses. Note: the range of transfer efficiencies extends from 30% for toilets to 90% for dishwashers.

#### Particulate Emission Factor for Soils

Inhalation of chemicals adsorbed to respirable particles ( $PM_{10}$ ) were assessed using a default PEF equal to  $1.316 \times 10^9 \text{ m}^3/\text{kg}$  that relates the contaminant concentration in soil with the concentration of respirable particles in the air due to fugitive dust emissions from contaminated soils. The relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g. years). This may not be an appropriate assumption for all sites.

The impact of the PEF on the resultant PRG concentration (that combines soil exposure pathways for ingestion, skin contact, and inhalation) can be assessed by downloading the PRG tables and displaying the hidden columns. With the exception of specific heavy metals, the PEF does not appear to significantly affect most soil PRGs. Equation 4-11 forms the basis for deriving a generic PEF for the inhalation pathway. For more details regarding specific parameters used in the PEF model, the reader is referred to *Technical Background Document for Soil Screening Guidance - Review Draft* (December 1994).

**Note:** the PEF considers windborne emissions and does not consider dust emissions from traffic or other forms of mechanical disturbance.

#### 4.2 Dermal Absorption of Contaminants in Soil:

Much uncertainty surrounds the determination of hazards associated with skin contact with soils. Thus far, chemical-specific absorption values for skin have been recommended for only five chemicals by EPA's Office of Research and Development. For all other chemicals, default absorption values for inorganics and organics are assumed to be 1 and 10 percent, respectively. An additional uncertainty is the lack of toxicity values for the dermal route. For screening purposes it is assumed that dermal toxicity values can be route-to-route extrapolated from oral values, but this may not always be an appropriate assumption and should be checked.

At 10 % skin absorption, the dermal dose is estimated to equal an ingestion dose for adults, using the best estimate default values in *Dermal Exposure Assessment: Principles and Applications* (EPA 1992). At 1 % absorption, the dermal dose is estimated to be 10% of the oral dose (i.e. based on an adult ingestion rate of 100 mg/day). Note: worker and children intake rates, 50 mg/day and 200 mg/day, respectively, yield somewhat different results.

dermal dose = ingestion dose

$$C_{SOIL} \times ABS \times AF \times SA = C_{SOIL} \times IR$$

$$ABS = \frac{(100mg/day)}{[(0.2mg/cm^2-day)(5000cm^2)]} = 0.10$$

#### 4.3 Exposure Factors:

Default exposure factors were obtained primarily from RAGS Supplemental Guidance Standard Default *Exposure Factors* (OSWER Directive, 9285.6-03) dated March 25, 1991 and supplemented with more recent information from U.S. EPA's Office of Solid Waste and Emergency Response, U.S. EPA's Office of Research and Development, and California EPA's Department of Toxic Substances Control (see Exhibit 4-1).

Because contact rates may be different for children and adults, carcinogenic risks during the first 30 years of life were calculated using age-adjusted factors. Use of age-adjusted factors are especially important for soil ingestion exposures, which are higher during childhood and decrease with age. However, for purposes of combining exposures across pathways, additional age-adjusted factors are used for inhalation and dermal exposures. These factors approximate the integrated exposure from birth until age 30 combining contact rates, body weights, and exposure durations for two age groups - small children and adults. Age-adjusted factors were obtained from RAGS PART B or developed by analogy.

For soils only, noncarcinogenic contaminants are evaluated in children separately from adults. No age-adjustment factor is used in this case. The focus on children is considered protective of the higher daily intake rates of soil by children and their lower body weight. For maintaining consistency, when evaluating soils, dermal and inhalation exposures are also based on childhood contact rates.

- (1) ingestion([mg•yr]/[kg•d]):

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} + \frac{(ED_r - ED_c) \times IRS_s}{BW_s}$$

- (2) skin contact([mg•yr]/[kg•d]):

$$SFS_{adj} = \frac{ED_c \times AF \times SA_c}{BW_c} + \frac{(ED_r - ED_c) \times AF \times SA_s}{BW_s}$$

- (3) inhalation ([m<sup>3</sup>•yr]/[kg•d]):

$$InhF_{adj} = \frac{ED_c \times IRA_c}{BW_c} + \frac{(ED_r - ED_c) \times IRA_s}{BW_s}$$

#### 4.4 PRG Equations:

The equations used to calculate the PRGs for carcinogenic and noncarcinogenic contaminants are presented in Equations 4-1 through 4-8. Calculations of PRGs are consistent with RAGS Part B (U.S. EPA 1991) but also consider updates to the RAGS Part B equations. Briefly, the methodology backcalculates a soil, air, or water concentration level from a target risk (for carcinogens) or hazard quotient (for noncarcinogens). The equations for soil combine across pathways for direct exposures (i.e. ingestion, skin contact, and inhalation). To evaluate route-specific contribution to the PRG concentration, the user can download the PRG table from California Regional Water Board's BBS mentioned above and display the hidden columns.

To calculate PRGs for volatile chemicals in soil, a chemical-specific volatilization factor is calculated per Equation 4-9. Because of its reliance on Henry's law, the VF model is applicable only when the contaminant concentration in soil water is at or below saturation (i.e. there is no free-phase contaminant present). This corresponds to the contaminant concentration in soil at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above this point, pure liquid-phase contaminant is expected in the soil. The updated equation for deriving (sat) is presented in Equation 4-10.

# EXHIBIT 4-1 STANDARD DEFAULT FACTORS

Symbol	Definition (units)	Default	Reference
CSFo	Cancer slope factor oral (mg/kg-d) <sup>-1</sup>	-	IRIS, HEAST, or ECAO
CSFi	Cancer slope factor inhaled (mg/kg-d) <sup>-1</sup>	-	IRIS, HEAST, or ECAO
RfDo	Reference dose oral (mg/kg-d)	-	IRIS, HEAST, or ECAO
RfDi	Reference dose inhaled (mg/kg-d)	-	IRIS, HEAST, or ECAO
TR	Target cancer risk	10 <sup>-6</sup>	-
THQ	Target hazard quotient	1	-
BWa	Body weight, adult (kg)	70 <sup>a</sup>	RAGS (Part A), EPA 1989 (EPA/540/1-89/002)
BWc	Body weight, child (kg)	15	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
AT	Averaging time - cancer (years)	70	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
SAa	25% Surface area, adult (cm <sup>2</sup> )	5000	Dermal Assessment, EPA 1992 (EPA/600/8-91/011B)
SAc	25% Surface area, child (cm <sup>2</sup> )	2000	Dermal Assessment, EPA 1992 (EPA/ 600/8-9/011B)
AF	Adherence factor (mg/cm <sup>2</sup> )	0.2	Dermal Assessment, EPA 1992 (EPA/ 600/8-9/011B)
ABS	Skin absorption (unitless):		
	- organics	0.1	PEA, Cal-EPA (DTSC, 1994)
	-Inorganics	0.01	PEA, Cal-EPA (DTSC, 1994)
IRaA	Inhalation rate - adult (m <sup>3</sup> /day)	20	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IRAc	Inhalation rate - child (m <sup>3</sup> /day)	10	RAGS (Part A), EPA 1989 (EPA/540/1-89/002)
IRWa	Drinking water ingestion - adult (L/day)	2	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
IRWc	Drinking water ingestion - child (L/day)	1	PEA, Cal-EPA (DTSC, 1994)
IRSa	Soil ingestion - adult (mg/day)	100	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IRSc	Soil ingestion - child (mg/day),	200	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IRSo	Soil ingestion - occupational (mg/day)	50	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
Efr	Exposure frequency - residential (d/y)	350	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
Efo	Exposure frequency - occupational (d/y)	250	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EDr	Exposure duration - residential (years)	30 <sup>b</sup>	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EDc	Exposure duration - child (years)	6	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
EDo	Exposure duration - occupational (years)	25	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IFSadj	Age-adjusted factors for carcinogens:		
SFSadj	Ingestion factor, soils ([mg·yr]/[kg·d])	114	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
InhFadj	Skin contact factor, soils ([mg·yr]/[kg·d])	503	By analogy to RAGS (Part B)
IFWadj	Inhalation factor ([m <sup>3</sup> ·yr]/[kg·d])	11	By analogy to RAGS (Part B)
	Ingestion factor, water ([L·yr]/[kg·d])	1.1	By analogy to RAGS (Part B)
VFw	Volatilization factor for water (unitless)	0.5	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
PEF	Particulate emission factor (m <sup>3</sup> /kg)	See below	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
VF <sub>s</sub>	Volatilization factor for soil (m <sup>3</sup> /kg)	See below	Technical Background Document for Draft SSL (EPA 1994)
sat	Soil saturation concentration (mg/kg)	See below	Technical Background Document for Draft SSL (EPA 1994)

## Footnote:

<sup>a</sup>Seventy years is the averaging time for carcinogens. For noncarcinogens, the averaging time is set equal to the exposure duration (AT = ED).

<sup>b</sup>Exposure duration for lifetime residents is assumed to be 30 years total. For carcinogens, exposures are combined for children (6 years) and adults (24 years).

## PRG EQUATIONS

**Soil Equations:** For soils, equations were based on three exposure routes (ingestion, skin contact, and inhalation).

### Equation 4-1: Combined Exposures to Carcinogenic Contaminants in Residential Soil

$$C(\text{mg/kg}) = \frac{TR \times AT \times 365\text{d/y}}{EF_r \left[ \left( \frac{IFS_{adj} \times CSF_o}{10^6 \text{mg/kg}} \right) + \left( \frac{SFS_{adj} \times ABS \times CSF_o}{10^6 \text{mg/kg}} \right) + \left( \frac{InhF_{adj} \times CSF_i}{VF_s^*} \right) \right]}$$

### Equation 4-2: Combined Exposures to Noncarcinogenic Contaminants in Residential Soil

$$C(\text{mg/kg}) = \frac{THQ \times BW_c \times ED_r \times 365\text{d/y}}{EF_r \times ED_c \left[ \left( \frac{1}{RfD_o} \times \frac{IRS_c}{10^6 \text{mg/kg}} \right) + \left( \frac{1}{RfD_o} \times \frac{SA_c \times AF \times ABS}{10^6 \text{mg/kg}} \right) + \left( \frac{1}{RfD_i} \times \frac{IRA_c}{VF_s^*} \right) \right]}$$

### Equation 4-3: Combined Exposures to Carcinogenic Contaminants in Industrial Soil

$$C(\text{mg/kg}) = \frac{TR \times BW_s \times AT \times 365\text{d/y}}{EF_o \times ED_o \left[ \left( \frac{IRS_o \times CSF_o}{10^6 \text{mg/kg}} \right) + \left( \frac{SA_s \times AF \times ABS}{10^6 \text{mg/kg}} \right) + \left( \frac{IRA_s \times CSF_i}{VF_s^*} \right) \right]}$$

### Equation 4-4: Combined Exposures to Noncarcinogenic Contaminants in Industrial Soil

$$C(\text{mg/kg}) = \frac{THQ \times BW_s \times ED_o \times 365\text{d/y}}{EF_o \times ED_o \left[ \left( \frac{1}{RfD_o} \times \frac{IRS_o}{10^6 \text{mg/kg}} \right) + \left( \frac{1}{RfD_o} \times \frac{SA_s \times AF \times ABS}{10^6 \text{mg/kg}} \right) + \left( \frac{1}{RfD_i} \times \frac{IRA_s}{VF_s^*} \right) \right]}$$

**Footnote:**

\*Use  $VF_s$  for volatile chemicals (defined as having a Henry's Law Constant [atm-m<sup>3</sup>/mol] greater than 10<sup>-5</sup> and a molecular weight less than 200 grams/mol) or PEF for non-volatile chemicals.



Tap Water Equations:

Equation 4-5: Ingestion and Inhalation Exposures to Carcinogenic Contaminants In Water

$$C(\text{ug/L}) = \frac{TR \times AT \times 365\text{d/y} \times 1000\text{ug/mg}}{EF_x [(IFW_{adj} \times CSF_o) + (VF_v \times InhF_{adj} \times CSF_1)]}$$

Equation 4-6: Ingestion and Inhalation Exposures to Noncarcinogenic Contaminants In Water

$$C(\text{ug/L}) = \frac{THQ \times BW_a \times ED_x \times 365\text{d/y} \times 1000\text{ug/mg}}{EF_x \times ED_x [(\frac{IRW_a}{RfD_o}) + (\frac{VF_v \times IRA_a}{RfD_1})]}$$

Air Equations:

Equation 4-7: Inhalation Exposures to Carcinogenic Contaminants In Air

$$C(\text{ug/m}^3) = \frac{TR \times AT \times 365\text{d/y} \times 1000\text{ug/mg}}{EF_x \times InhF_{adj} \times CSF_1}$$

Equation 4-8: Inhalation Exposures to Noncarcinogenic Contaminants In Air

$$C(\text{ug/m}^3) = \frac{THQ \times RfD_1 \times BW_a \times ED_x \times 365\text{d/y} \times 1000\text{ug/mg}}{EF_x \times ED_x \times IRA_a}$$

## SOIL-TO-AIR VOLATILIZATION FACTOR (VF<sub>s</sub>)

### Equation 4-9: Derivation of the Volatilization Factor

$$VF_s (m^3/kg) = (Q/C) \times \frac{(3.14 \times \alpha \times T)^{1/2}}{(2 \times D_{ei} \times \theta_a \times K_{sa})} \times 10^{-4} m^2/cm^2$$

where:

$$\alpha = \frac{D_{ai} \times \theta_a}{\theta_a + [(p_s)(1-\theta_a)/K_{sa}]}$$

Parameter	Definition (units)	Default
VF <sub>s</sub>	Volatilization factor (m <sup>3</sup> /kg)	--
Q/C	Inverse of the mean conc. at the center of a 0.5-acre square source (g/m <sup>2</sup> -s per kg/m <sup>3</sup> )	68.81
T	Exposure interval (s)	7.9 x 10 <sup>5</sup>
Dei	Effective diffusivity (cm <sup>2</sup> /s)	Di(θ <sub>a</sub> <sup>3.33</sup> /n <sup>2</sup> )
θ <sub>a</sub>	Air filled soil porosity (L <sub>air</sub> /L <sub>soil</sub> )	0.28 or n-wp <sub>s</sub>
Di	Diffusivity in air (cm <sup>2</sup> /s)	Chemical-specific
n	Total soil porosity (L <sub>porv</sub> /L <sub>soil</sub> )	0.43 (loam)
w	Average soil moisture content (g <sub>water</sub> /g <sub>soil</sub> or cm <sup>3</sup> <sub>water</sub> /g <sub>soil</sub> )	0.1
p <sub>s</sub>	Dry soil bulk density (g/cm <sup>3</sup> )	1.5 or (1 - n)p <sub>s</sub>
p <sub>a</sub>	Soil particle density (g/cm <sup>3</sup> )	2.65
K <sub>sa</sub>	Soil-air partition coefficient (g-soil/cm <sup>3</sup> -air)	(H/Kd) x 41 (41 is a conversion factor)
H	Henry's Law constant (atm-m <sup>3</sup> /mol)	Chemical-specific
K <sub>d</sub>	Soil-water partition coefficient (cm <sup>3</sup> /g)	K <sub>oc</sub> x f <sub>oc</sub>
k <sub>oc</sub>	Soil organic carbon/water partition coefficient (cm <sup>3</sup> /g)	Chemical-specific
f <sub>oc</sub>	Fraction organic carbon content of soil (g/g)	0.02 or site-specific

## SOIL SATURATION CONCENTRATION (sat)

Equation 4-10: Derivation of the Soil Saturation Limit

$$sat = \frac{S}{\rho_b} (K_d \rho_b + \theta_w + H' \theta_a)$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
sat	Soil saturation concentration (mg/kg)	—
S	Solubility in water (mg/L-water)	Chemical-specific
$\rho_b$	Dry soil bulk density (kg/L)	1.5 or $(1 - n)\rho_s$
n	Total soil porosity ( $L_{pore}/L_{soil}$ )	0.43 (loam)
$\rho_s$	Soil particle density (kg/L)	2.65
$K_d$	Soil-water partition coefficient (L/kg)	$K_{oc} \times f_{oc}$ (organics)
$k_{oc}$	Soil organic carbon/water partition coefficient (L/kg)	Chemical-specific
$f_{oc}$	Fraction organic carbon content of soil (g/g)	0.02 or site-specific
$\theta_w$	Water-filled soil porosity ( $L_{water}/L_{soil}$ )	0.15 or $w\rho_b$
$\theta_a$	Air filled soil porosity ( $L_{air}/L_{soil}$ )	0.28 or $n - w\rho_b$
w	Average soil moisture content ( $kg_{water}/kg_{soil}$ or $L_{water}/kg_{soil}$ )	0.1
H'	Henry's Law constant (unitless)	$H \times 41$ , where 41 is a units conversion factor
H	Henry's Law constant (atm-m <sup>3</sup> /mol)	Chemical-specific

## SOIL-TO-AIR PARTICULATE EMISSION FACTOR (PEF)

Equation 4-11: Derivation of the Particulate Emission Factor

$$PEF(m^3/kg) = Q/C \times \frac{3600s/h}{0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
PEF	Particulate emission factor (m <sup>3</sup> /kg)	1. 316 x 10 <sup>9</sup>
Q/C	Inverse of the mean concentration at the center of a 0.5-acre-square source (g/m <sup>2</sup> -s per kg/m <sup>3</sup> )	90.80
V	Fraction of vegetative cover (unitless)	0.5
U <sub>m</sub>	Mean annual windspeed (m/s)	4.69
U <sub>t</sub>	Equivalent threshold value of windspeed at 7 m (m/s)	11.32
F(x)	Function dependent on U <sub>m</sub> /U <sub>t</sub> , derived using Cowherd (1985) (unitless)	0.194

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ATTACHMENT A  
PHYSICAL-CHEMICAL CONSTANTS USED IN CALCULATING SOIL PRGs FOR VOLATILE ORGANIC CHEMICALS

	MW (g/mol)	Henry's Law (atm-cm <sup>3</sup> /mol)	Diffusivity in Air (cm <sup>2</sup> /s)	Koc (ml/g)	Water Solubility (mg/l)	References
Acetone	58	0.000021	0.100	2.2	1000000	1,2
Acrylonitrile	53	0.000088	0.110	0.9	79000	1,2
Ammonia	17	0.000320	0.260	3.1	530000	1,2
Benzene	78	0.005500	0.088	65.0	1800	1,2,3
Benzyl chloride	130	0.000051	0.067	50.0	3300	1,2
Bis(2-chloroethyl)ether	140	0.000290	0.070	14.0	10000	1,2,4
Bis(2-chloroisopropyl)ether	170	0.000110	0.083	81.0	1700	1,2
Bis(chloromethyl)ether	120	0.000200	0.089	1.2	22000	1,2
Bromodichloromethane	160	0.001600	0.080	100.0	4700	2,4
Bromoethene (Surrogate = Bromomethane)	108	0.006200	0.100	130.0	18000	2,4
Bromomethane	95	0.006200	0.100	130.0	18000	2,4
1,3-Butadiene	54	0.180000	0.098	120.0	740	1,2
Carbon disulfide	76	0.012000	0.110	54.0	2900	1,2
Carbon tetrachloride	150	0.024000	0.080	110.0	760	2,3
Chlorine dioxide						
Chloroacetaldehyde	150	0.003500	0.072	160.0	470	2,3
2-Chloroacetophenone (Surrogate = Chlorobenzene)	110	0.003500	0.072	160.0	470	2,3
Chlorobenzene	88	0.032000	0.110	50.0	660	2,4
2-Chloro-1,3-butadiene	93	0.032000	0.110	50.0	660	2,4
1-Chlorobutane (Surrogate = 2-Chloro-1,3-butadiene)	120	0.100000	0.080	58.0	280	1,2,4
Chlorodifluoromethane (Surrogate = Dichlorodifluoromethane)						
1-Chloroethyl vinyl ether	120	0.003800	0.089	31.0	8200	1,2,4
Chloroform	51	0.024000	0.110	35.0	8200	1,2,4
Chloromethane	79	0.002300	0.080	51.0	2700	1,2
2-Chloropropane	127	0.003500	0.072	160.0	470	2,3
o-Chlorotoluene	70	0.240000	0.091	840.0	20	1,2
Crotonaldehyde (Surrogate = Methyl methacrylate)	70	0.006400	0.075	220.0	150	2,3
Cumene (Surrogate = Ethylbenzene)	120	0.000320	0.073	28.0	3400	2,3
1,2-Dibromoethane	150	0.001900	0.130	1100.0	100	2,3
1,2-Dichlorobenzene	150	0.001900	0.130	1200.0	120	2,3
1,3-Dichlorobenzene	150	0.001600	0.130	1200.0	79	2,3
1,4-Dichlorobenzene	122	0.032000	0.110	50.0	660	1,2
1,4-Dichloro-2-butene (Surrogate = 2-Chloro-1,3-butadiene)	120	0.100000	0.080	58.0	280	1,2,4
Dichlorodifluoromethane	89	0.004300	0.091	30.0	5500	2,3
1,1-Dichloroethane	99	0.001200	0.091	14.0	8700	2,3
1,2-Dichloroethane (EDC)	97	0.150000	0.079	65.0	400	2,3
1,4-Dichloroethylene	97	0.006600	0.079	59.0	6300	2,3
1,2-Dichloroethylene (trans)	97	0.006600	0.079	59.0	6300	2,3
1,2-Dichloroethylene (mixture)	110	0.003600	0.080	51.0	2700	1,2,4
1,2-Dichloropropane	110	0.001300	0.080	48.0	2800	1,2
1,3-Dichloropropane	110	0.001300	0.081	48.0	2800	1,2
1,3-Dichloropropene						
Dicyclopentadiene	45	0.000090	0.120	2.2	100000	1,2
Dimethylamine	88	0.000011	0.085	3.5	430000	1,2
1,4-Dioxane	93	0.000032	0.088	3.5	60000	1,2
Epichlorohydrin	100	0.240000	0.091	840.0	20	1,2
Ethyl acrylate (Surrogate = Methyl methacrylate)	110	0.007900	0.075	220.0	680	2,3
Ethylbenzene	44	0.000076	0.130	2.2	1000000	1,2
Ethylene oxide	65	0.011000	0.100	15.0	5700	2,3
Ethyl chloride	74	0.000013	0.070	14.0	10000	1,2,4
Ethyl ether	120	0.240000	0.091	840.0	20	1,2
Ethyl methacrylate (Surrogate = Methyl methacrylate)						
Hydrogen sulfide	93	0.000088	0.110	0.9	79000	1,2
Methacrylonitrile (Surrogate = Acrylonitrile)	74	0.000021	0.100	2.2	1000000	1,2
Methyl acetate (Surrogate = Acetone)	100	0.240000	0.091	840.0	20	1,2
Methyl acrylate (Surrogate = Methyl methacrylate)	85	0.002600	0.100	8.8	13200	2,3
Methylene chloride	72	0.000027	0.090	4.5	270000	2,3
Methyl ethyl ketone	119	0.002300	0.071	360.0	300	2,3
Methyl styrene (mixture) (Surrogate = Styrene)	119	0.002300	0.071	360.0	300	2,3
Methyl styrene (alpha) (Surrogate = Styrene)						
Nitrogen dioxide						
2-Nitropropane						
Polynuclear aromatic hydrocarbons						
Acenaphthene	150	0.001200	0.064	4600.0	4	2,3
Anthracene	180	0.000034	0.058	13000.0	0	2,3
Fluorene	170	0.000064	0.061	7900.0	2	2,3
Naphthalene	130	0.001300	0.069	1300.0	31	2,3
Phenanthrene	180	0.000040	0.058	14000.0	1	2,3
Propylene oxide	58					
Styrene	100	0.002300	0.071	360.0	300	2,3
1,1,1,2-Tetrachloroethane	170	0.000380	0.073	54.0	2900	1,2
1,1,2,2-Tetrachloroethane	170	0.000500	0.073	220.0	2900	2,3
Tetrachloroethylene (PCE)	170	0.023000	0.072	660.0	150	2,3
Tetrahydrofuran	72	0.000110	0.089			2,3
Toluene	92	0.006600	0.078	260.0	520	2,3
1,2,4-Trichlorobenzene	180	0.002300	0.062	9200.0	30	1,2
1,1,1-Trichloroethane	130	0.002800	0.080	150.0	950	2,3
1,1,2-Trichloroethane	130	0.001200	0.080	56.0	4500	2,3
1,1,2-Trichloroethane (TCE)	130	0.008920	0.081	130.0	1000	2,3
Trichloroethylene (TCE)	137	0.097000	0.087	160.0	1100	1,2,4
Trichlorofluoromethane	147	0.003600	0.080	51.0	2700	1,2
1,1,2-Trichloropropane (Surrogate = 1,2-Dichloropropane)	147	0.003600	0.080	51.0	2700	1,2
1,2,3-Trichloropropane (Surrogate = 1,2-Dichloropropane)	146	0.001300	0.081	48.0	2800	1,2
1,2,3-Trichloropropene (Surrogate = 1,3-Dichloropropene)	186	0.058000	0.087	160.0	1100	1,2,4
1,1,2-Trichloro-1,2,2-trifluoroethane (S = Trichlorofluoromethane)	86	0.000090	0.120	2.2	1000000	1,2
Triethylamine (Surrogate = Dimethylamine)	63	0.700000	0.110	57.0	1100	2,3
Vinyl chloride	110	0.006900	0.087	240.0	200	2,3
m-Xylene	110	0.004900	0.087	240.0	200	2,3
o-Xylene	110	0.007000	0.087	240.0	200	2,3
p-Xylene	110	0.005200	0.087	240.0	200	2,3



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IX

75 Hawthorne Street  
San Francisco, CA 94105-3901

August 1, 1994

Subject: Region IX Preliminary Remediation Goals (PRGs) Second Half 1994

From: Stanford J. Smucker, Ph.D.  
Regional Toxicologist (H-9-3)  
Technical Support Section

To: PRG Table Mailing List

Please find the update to the Region IX PRG table. The table has been revised to reflect the most current EPA toxicological and risk assessment information. Updates to EPA toxicity values were obtained from IRIS through July 1994 and HEAST through March 1994. Age-adjustment factors have been added to better evaluate residential exposures to carcinogens. In addition, the soil saturation equation has been corrected, leading to approximately a ten fold higher saturation concentration in soils.

The PRG table provides useful risk-based information for Region IX risk assessors and managers. However, the table has no official status and may be in conflict with local state requirements. Four problem chemicals (cadmium, chromium, nickel, and DBCP) have been identified by Cal-EPA's Department of Toxic Substances Control. California soil values differ significantly, by a factor of four or more, for these chemicals. To address these concerns, the "Cal-modified PRG" concentrations, based on PEA (1994) guidance, are included with the federal values and should be used in California when screening a site.

In general, PRGs should be used as a predictor of single-contaminant risk estimates for a specific environmental media (e.g. soil, air, and tap water). However, multiple pollutant risks can also be estimated using PRGs (see Screening Risk below). This procedure is somewhat more complicated as it requires gathering additional information, either by downloading the table to display the hidden columns or by using the equations presented in the text for calculating additional concentration terms not provided in the print out.

A contaminant concentration that exceeds a PRG level does not, in itself, mean that there is an unacceptable health threat. However, exceedances should be evaluated further. It is recommended that the reader verify the numbers with a toxicologist because the toxicity/exposure information in the table may contain errors or default assumptions that need to be refined based on further evaluation.

If you are not currently on the PRG mailing list, but would like to be, please make the request through EPA's project manager working on your site. Or, simply download the file (PRG2ND94.ZIP) from California Regional Water Board's BBS [(510) 286-0404]. If you find an error please send me a note via fax at (415) 744-1916.

## 1.0 INTRODUCTION

The Region IX PRG Table combines EPA toxicity values, updated biannually, with reasonable maximum exposure (RME) factors to estimate concentrations in environmental media (e.g. soil, air, and water) that are generally agreed to be "safe" for humans. Above these levels, there may be enough concern to warrant further evaluation of risks.

PRG concentrations presented in the Tables can be used to screen pollutants in environmental media, trigger further investigation, and provide an initial cleanup goal if applicable. When considering PRGs as initial cleanup goals, residential concentrations should be used for maximum beneficial uses of a property. Industrial concentrations for soil only are included in the table as an alternative goal, but industrial concentrations should not be used for screening a site. They are meant to provide the manager with an alternative preliminary goal for sites zoned heavy industrial.

Before applying PRGs as screening tools or initial cleanup goals, the user of the table should consider whether the exposure pathways at the site are fully accounted for in the PRG calculation. Region IX PRG concentrations are based on direct exposures (i.e. ingestion, dermal contact, and inhalation) for specific land-use conditions and do not consider impact to groundwater or ecological receptors. To determine the appropriateness of Region IX PRGs, the following questions should be asked:

- Are there potential ecological concerns?
- Is there potential for land use other than those covered by the PRGs (that is, residential and industrial)?
- Are there other likely human exposure pathways that were not considered in development of the PRGs (e.g. impact to groundwater, local fish consumption; raising beef, dairy, or other livestock)?
- Are there unusual site conditions (e.g. large areas of contamination, high fugitive dust levels, potential for indoor air contamination)?

If any of these four conditions exist, the PRG may need to be modified to reflect this new information. In general, PRGs are refined in the site conceptual model developed as part of a site-specific risk assessment.

### DISCLAIMER

Preliminary remediation goals (PRGs) focus on dominant exposure pathways and may not consider all exposure pathways encountered at CERCLA/RCRA sites (Exhibit 1-1). PRGs do not consider impact to groundwater or address ecological concerns. PRGs are specifically not intended as a (1) stand-alone decision-making tool, (2) as a substitute for EPA guidance for preparing baseline risk assessments, or (3) a rule to determine if a waste is hazardous under RCRA.

The guidance set out in this document is not final Agency action. It is not intended, nor can it be relied upon to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided herein, or act at variance with the guidance, based on an analysis of specific circumstances. The Agency also reserves the right to change this guidance at any time without public notice.



**EXHIBIT 1-1**  
**TYPICAL EXPOSURE PATHWAYS BY MEDIUM**  
**FOR RESIDENTIAL AND INDUSTRIAL LAND USES\***

EXPOSURE PATHWAYS, ASSUMING:		
MEDIUM	RESIDENTIAL LAND USE	INDUSTRIAL LAND USE
Ground Water	<i>Ingestion from drinking</i>	Ingestion from drinking
	<i>Inhalation of volatiles</i>	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
Surface Water	<i>Ingestion from drinking</i>	Ingestion from drinking
	<i>Inhalation of volatiles</i>	Inhalation of volatiles
	Dermal absorption from bathing	Dermal absorption
	Ingestion during swimming	
	Ingestion of contaminated fish	
Soil	<i>Ingestion</i>	<i>Ingestion</i>
	<i>Inhalation of particulates</i>	<i>Inhalation of particulates</i>
	<i>Inhalation of volatiles</i>	<i>Inhalation of volatiles</i>
	Exposure to indoor air from soil gas	Exposure to indoor air from soil gas
	Exposure to ground water contaminated by soil leachate	Exposure to ground water contaminated by soil leachate
	Ingestion via plant uptake	Inhalation of particulates from trucks and heavy equipment
	<i>Dermal absorption</i>	<i>Dermal absorption</i>

Footnote:

\*Exposure pathways considered in the PRG calculations are indicated in boldface italics.

## 2.0 READING THE PRG TABLE

### 2.1 General Considerations:

PRGs are health-based concentrations that correspond to either a 1 in a million ( $10^{-6}$ ) cancer risk or a "safe" reference dose (RfD), whichever is lower. PRG concentrations based on cancer and noncancer concerns are indicated by "ca" and "nc", respectively. Cancer-causing agents may have additional non-cancer PRGs not listed in the Tables. These can be obtained by downloading file (PRG2ND94.ZIP) from California Regional Water Board's Bulletin Board System at [(510)286-0404] or using the calculations provided below.

In general, PRG concentrations in the table are risk-based but for soil there are two important exceptions: 1) for several volatile chemicals PRGs are based on soil saturation equation ("sat") (see below), and 2) for relatively less toxic inorganic and semivolatile contaminants, a non-risk based "ceiling limit" concentration is given as  $10^{-5}$  mg/kg "max". PRG concentrations that are not risk-based (i.e. either "sat" or "max") should be segregated before screening multiple pollutant risks.

### 2.2 Toxicity Values:

EPA toxicity values, known as noncarcinogenic reference doses (RfD) and carcinogenic slope factors (SF) were obtained from IRIS through July 1994, HEAST through March 1994, and ECAO-Cincinnati. The priority among sources of toxicological constants used are as follows: (1) IRIS (indicated by "i"), (2) HEAST ("h"), (3) ECAO-Cincinnati ("e"), and (4) withdrawn from IRIS or HEAST ("x"). Note in some cases, state toxicity values may differ from the federal numbers or even be promulgated as ARARs; these and the resultant PRGs should also be considered as initial cleanup goals.

Route-to-route extrapolations ("r") were frequently used when there were no toxicity values available for a given route. Oral cancer slope factors ("oSF") and reference doses ("oRfD") were used for both oral and inhaled exposures for organic compounds lacking inhalation values. Also, inhalation slope factors ("iSF") and inhalation reference doses ("iRfD") were often used for both inhaled and oral exposures for organic compounds lacking oral values.

An additional route-to-route extrapolation is the use of oral toxicity values for evaluating dermal exposures. Although route-to-route methods are a useful screening procedure, the assumptions may need to be further evaluated in a site-specific risk assessment.

### 2.3 Soil Factors:

Chemical-specific information for soils, volatilization factors ("VF\_s") and skin absorption factors ("ABS"), are listed in the table to provide additional assumptions used to calculate soil PRGs. For volatile chemicals, the "VF\_s" term was incorporated into the PRG equations to address long-term inhalation exposures. Volatile organic chemicals (VOCs) are indicated by "1" in the VOC column of the Table and are defined as those chemicals having a Henry's Law constant greater than  $10^{-5}$  (atm-m<sup>3</sup>/mol) and a molecular weight less than 200 g/mole).

Chemical-specific "ABS" values are provided for arsenic, cadmium, pentachlorophenol, PCBs, and dioxin as recommended by EPA's Office of Research and Development (1994) for the evaluation of contaminant absorption through the skin. Otherwise, default skin absorption fractions are assumed to be 0.01 and 0.10, for inorganics and organics, respectively.

## 2.4 Risk Screening:

A suggested stepwise approach for screening sites with PRGs is as follows:

- Perform an extensive records search and compile existing data
- Identify site contaminants in the PRG Table. Record the PRG concentrations for various media and note whether PRG is based on cancer risk (indicated by "ca") or noncancer hazard (indicated by "nc"). Segregate cancer PRGs from non-cancer PRGs and exclude (but don't eliminate) non-risk based PRGs ("sat" or "max").
- For cancer risk estimates, take the site-specific concentration (maximum or 95 UCL) and divide by the PRG concentrations that are designated for cancer evaluation ("ca"). Multiply this ratio by  $10^{-6}$  to estimate chemical-specific risk. For multiple pollutants, simply add the risk for each chemical:

$$Risk = 10^{-6} \cdot \left[ \left( \frac{CONC_x}{PRG_x} \right) + \left( \frac{CONC_y}{PRG_y} \right) + \left( \frac{CONC_z}{PRG_z} \right) \right]$$

- For non-cancer hazard estimates. Divide concentration term by its respective non-cancer PRG designated as "nc" and sum the ratios for multiple contaminants. [Note that carcinogens may also have an associated non-cancer PRG that is not listed in the printed copy of the table and these will also need to be obtained in order to complete the non-cancer evaluation.] The non-cancer ratio represents a hazard index (HI). A hazard index of 1 or less is generally considered safe. A ratio greater than 1 suggests further evaluation:

$$Hazard\ Index = \left[ \left( \frac{CONC_x}{PRG_x} \right) + \left( \frac{CONC_y}{PRG_y} \right) + \left( \frac{CONC_z}{PRG_z} \right) \right]$$

For more information on screening site risks, the reader should contact EPA Region IX's Technical Support Section.

### 3.0 TECHNICAL SUPPORT DOCUMENTATION

PRGs consider direct exposure hazards to chemicals from contact with complex media, soils, air, and water. The emphasis of the PRG equations and technical discussion are aimed at developing initial goals for soils, since this is an area where few standards exist. For air and water, additional reference concentrations or standards are available for many chemicals (e.g. MCLGs and NAAQS) and consequently the discussion of these media are brief.

#### 3.1 Volatile Chemicals in Soil and Water:

Volatile chemicals, defined as those chemicals having a Henry's Law constant greater than  $10^{-5}$  (atm-m<sup>3</sup>/mol) and a molecular weight less than 200 g/mole, were screened for inhalation exposures using a volatilization factor in the PRG calculations for soil and water (RAGS Part B).

Volatilization factors for soils (VF<sub>s</sub>) are chemical-specific and were calculated from physical-chemical information obtained from a number of sources including *Superfund Exposure Assessment Manual* (reference "1")(SEAM, EPA 1988), *Superfund Public Health Evaluation Manual* (reference "2")(EPA 1986), *Subsurface Contamination Reference Guide* (reference "3")(EPA 1990) and *Fate and Exposure Data* (reference "4")(Howard 1991) and are presented in Attachment A. In those cases where Diffusivity Coefficients (Di) were not provided in existing literature, Di's were calculated using Fuller's Method described in SEAM. A surrogate VF for contaminants in soil was required for some chemicals that lacked physico-chemical information. In these cases, a proxy chemical of similar structure was used that may over- or under-estimate the PRG for soils.

The basic principle of the VF model is applicable only if the soil contaminant concentration is at or below soil saturation. If the PRG calculated using VF<sub>s</sub> was greater than the calculated "sat", the PRG was set equal to "sat" in accordance with Risk Assessment Guidance for Superfund - Part B (EPA, 1991).

For tap water, an upperbound volatilization constant (VF<sub>w</sub>) is used that is based on all uses of household water (e.g. showering, laundering, and dish washing). Certain assumptions were made. For example, it is assumed that the volume of water used in a residence for a family of four is 720 L/day, the volume of the dwelling is 150,000 L and the air exchange rate is 0.25 air changes/hour (Andelman in RAGS Part B). Furthermore, it is assumed that the average transfer efficiency weighted by water use is 50 percent [i.e. half of the concentration of each chemical in water will be transferred into air by all water uses. Note: the range of transfer efficiencies extends from 30% for toilets to 90% for dishwashers.

#### 3.2 Dermal Absorption of Contaminants in Soil:

Much uncertainty surrounds the determination of hazards associated with skin contact with soils. Thus far, chemical-specific absorption values for skin have been recommended for only five chemicals by EPA's Office of Research and Development. For all other chemicals, default absorption values for inorganics and organics are assumed to be 1 and 10 percent, respectively. An additional uncertainty is the lack of toxicity values for the dermal route. For screening purposes it is assumed that dermal toxicity values can be route-to-route extrapolated from oral values, but this may not always be an appropriate assumption and should be checked.

At 10 % skin absorption, the dermal dose is estimated to equal an ingestion dose for adults, using the best estimate default values in *Dermal Exposure Assessment: Principles and Applications* (EPA 1992). At 1 % absorption, the dermal dose is estimated to be 10% of the oral dose (i.e. based on an adult

ingestion rate of 100 mg/day). Note: worker and children intake rates, 50 mg/day and 200 mg/day, respectively, yield somewhat different results.

dermal dose = ingestion dose

$$C_{SOIL} \cdot ABS \cdot AF \cdot SA = C_{SOIL} \cdot IR$$

$$ABS = \frac{(100 \text{ mg/day})}{[(0.2 \text{ mg/cm}^2\text{-day}) (5000 \text{ cm}^2)]} = 0.10$$

### 3.3 Chemicals Adsorbed to Airborne Particles:

Inhalation of chemicals adsorbed to respirable particles ( $PM_{10}$ ) were assessed using a default particulate emission factor (PEF) equal to  $4.63 \times 10^9 \text{ m}^3/\text{kg}$  that relates the contaminant concentration in soil with the concentration of respirable particles in the air due to fugitive dust emissions from contaminated soils. The relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g. years). This may not be an appropriate assumption for all sites.

With the possible exception of cadmium, chromium, and nickel, inhalation of airborne particles (under typical conditions) does not significantly affect the PRG for soils. For more details regarding specific parameters used in the PEF model, the reader is referred to RAGS Part B (EPA, 1991).

### 3.4 Exposure Factors:

Default exposure factors were obtained primarily from RAGS Supplemental Guidance Standard Default *Exposure Factors* (OSWER Directive, 9285.6-03) dated March 25, 1991 and supplemented with more recent information from U.S. EPA's Office of Solid Waste and Emergency Response, U.S. EPA's Office of Research and Development, and California EPA's Department of Toxic Substances Control (see Exhibit 3-1).

Because contact rates may be different for children and adults, carcinogenic risks during the first 30 years of life were calculated using age-adjusted factors. Use of age-adjusted factors are especially important for soil ingestion exposures, which are higher during childhood and decrease with age. However, for purposes of combining exposures across pathways, additional age-adjusted factors are used for inhalation and dermal exposures. These factors approximate the integrated exposure from birth until age 30 combining contact rates, body weights, and exposure durations for two age groups - small children and adults. Age-adjusted factors were obtained from RAGS PART B or developed by analogy.

(1) ingestion([mg•yr]/[kg•d]):

$$IFS_{adj} = \frac{ED_c \cdot IRS_c}{BW_c} + \frac{(ED_r - ED_c) \cdot IRS_a}{BW_a}$$

(2) skin contact([mg•yr]/[kg•d]):

$$SFS_{adj} = \frac{ED_c \cdot SL \cdot SA_c}{BW_c} + \frac{(ED_r - ED_c) \cdot SL \cdot SA_a}{BW_a}$$

(3) inhalation ([m<sup>3</sup>•yr]/[kg•d]):

$$InhF_{adj} = \frac{ED_c \cdot IRA_c}{BW_c} + \frac{(ED_r - ED_c) \cdot IRA_a}{BW_a}$$

For soils only, noncarcinogenic contaminants are evaluated in children separately from adults. No age-adjustment factor is used in this case. The focus on children is considered protective of the higher daily intake rates of soil by children and their lower body weight. For maintaining consistency, when evaluating soils, dermal and inhalation exposures are also based on childhood contact rates.

### 3.5 PRG Equations:

The equations used to calculate the PRGs for carcinogenic and noncarcinogenic contaminants are presented in Equations 3-1 thru 3-8. Calculations of PRGs are consistent with RAGS Part B (U.S. EPA 1991) but also consider updates to the RAGS Part B equations. Briefly, the methodology backcalculates a soil, air, or water concentration level from a target risk (for carcinogens) or hazard quotient (for noncarcinogens). The equations for soil combine across pathways for direct exposures (i.e. ingestion, skin contact, and inhalation). To evaluate route-specific contribution to the PRG concentration, the reader may want to download the PRG table from California Regional Water Board's BBS mentioned above and display the hidden columns.

To calculate PRGs for volatile chemicals in soil, a chemical-specific volatilization factor is calculated per Equation 3-9 (page 12). Because of its reliance on Henry's law, the VF model is applicable only when the contaminant concentration in soil water is at or below saturation (i.e. there is no free-phase contaminant present). This corresponds to the contaminant concentration in soil at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above this point, pure liquid-phase contaminant is expected in the soil. The updated equation for deriving  $C_{sat}$  is presented in Equation 3-10.

### EXHIBIT 3-1 STANDARD DEFAULT FACTORS

<u>Symbol</u>	<u>Definition (units)</u>	<u>Default</u>	<u>Reference</u>
CSFo	Cancer slope factor oral (mg/kg-d)-1	—	IRIS, HEAST, or ECAO
CSFi	Cancer slope factor inhaled (mg/kg-d)-1	—	IRIS, HEAST, or ECAO
RfDo	Reference dose oral (mg/kg-d)	—	IRIS, HEAST, or ECAO
RfDi	Reference dose inhaled (mg/kg-d)	—	IRIS, HEAST, or ECAO
TR	Target cancer risk	10-6	—
THQ	Target hazard quotient	1	—
BW <sub>a</sub>	Body weight, adult (kg)	70 <sup>a</sup>	RAGS (Part A), EPA 1989 (EPA/540/1-89/002)
BW <sub>c</sub>	Body weight, child (kg)	15	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
AT	Averaging time - cancer (years)	70	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
SA <sub>a</sub>	25% Surface area, adult (cm <sup>2</sup> )	5000	Dermal Assessment, EPA 1992 (EPA/600/8-91/011B)
SA <sub>c</sub>	25% Surface area, child (cm <sup>2</sup> )	2000	Dermal Assessment, EPA 1992 (EPA/ 600/8-9/011B)
AF	Adherence factor (mg/cm <sup>2</sup> )	0.2	Dermal Assessment, EPA 1992 (EPA/ 600/8-9/011B)
ABS	Skin absorption (unitless):		
	— organics	0.1	PEA, Cal-EPA (DTSC, 1994)
	— inorganics	0.01	PEA, Cal-EPA (DTSC, 1994)
IR <sub>a</sub>	Inhalation rate - adult (m <sup>3</sup> /day)	20	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IR <sub>c</sub>	Inhalation rate - child (m <sup>3</sup> /day)	10	RAGS (Part A), EPA 1989 (EPA/540/1-89/002)
IRW <sub>a</sub>	Drinking water ingestion - adult (L/day)	2	RAGS(Part A), EPA 1989 (EPA/540/1-89/002)
IRW <sub>c</sub>	Drinking water ingestion - child (L/day)	1	PEA, Cal-EPA (DTSC, 1994)
IR <sub>sa</sub>	Soil ingestion - adult (mg/day)	100	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IR <sub>sc</sub>	Soil ingestion - child (mg/day),	200	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
IR <sub>so</sub>	Soil ingestion - occupational (mg/day)	50	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
E <sub>fr</sub>	Exposure frequency - residential (d/y)	350	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
E <sub>fo</sub>	Exposure frequency - occupational (d/y)	250	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
E <sub>dr</sub>	Exposure duration - residential (years)	30 <sup>b</sup>	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
E <sub>dc</sub>	Exposure duration - child (years)	6	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
E <sub>do</sub>	Exposure duration - occupational (years)	25	Exposure Factors, EPA 1991 (OSWER No. 9285.6-03)
	Age-adjusted factors for carcinogens:		
IFS <sub>adj</sub>	Ingestion factor, soils ((mg-yr)/(kg-d))	114	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
SFS <sub>adj</sub>	Skin contact factor, soils ((mg-yr)/(kg-d))	503	By analogy to RAGS (Part B)
InhF <sub>adj</sub>	Inhalation factor ((m <sup>3</sup> -yr)/(kg-d))	11	By analogy to RAGS (Part B)
VF <sub>w</sub>	Volatilization factor for water (unitless)	0.5	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
PEF	Particulate emission factor (m <sup>3</sup> /kg)	See below	RAGS(Part B), EPA 1991 (OSWER No. 9285.7-01B)
VF <sub>s</sub>	Volatilization factor for soil (m <sup>3</sup> /kg)	See below	OSWER (EPA 1993, communication from Janine Dinan)
C <sub>sat</sub>	Soil saturation concentration (mg/kg)	See below	OSWER (EPA 1994, communication from Janine Dinan)

**Footnote:**

<sup>a</sup>Seventy years is the averaging time for carcinogens. For noncarcinogens, the averaging time is set equal to the exposure duration (AT = ED).

<sup>b</sup>Exposure duration for lifetime residents is assumed to be 30 years total. For carcinogens, exposures are combined for children (6 years) and adults (24 years).

## PRG EQUATIONS

**Soil Equations:** For soils, equations were based on three exposure routes (ingestion, skin contact, and inhalation).

**Equation 3-1: Direct Exposures to Carcinogenic Contaminants in Residential Soil**

$$C(\text{mg/kg}) = \frac{TR \cdot AT \cdot 365 \text{ d/y}}{EF_x \left[ \left( \frac{IFS_{adj} \cdot CSF_o}{10^6 \text{ mg/kg}} \right) + \left( \frac{SFS_{adj} \cdot ABS \cdot CSF_o}{10^6 \text{ mg/kg}} \right) + \left( \frac{InhF_{adj} \cdot CSF_i}{VF^a} \right) \right]}$$

**Equation 3-2: Direct Exposures to Noncarcinogenic Contaminants in Residential Soil**

$$C(\text{mg/kg}) = \frac{THQ \cdot BW_c \cdot ED_x \cdot 365 \text{ d/y}}{EF_x \cdot ED_c \left[ \left( \frac{1}{RfD_o} \cdot \frac{IRS_c}{10^6 \text{ mg/kg}} \right) + \left( \frac{1}{RfD_o} \cdot \frac{SA_c \cdot SL \cdot ABS}{10^6 \text{ mg/kg}} \right) + \left( \frac{1}{RfD_i} \cdot \frac{IRA_c}{VF^a} \right) \right]}$$

**Equation 3-3: Direct Exposures to Carcinogenic Contaminants in Industrial Soil**

$$C(\text{mg/kg}) = \frac{TR \cdot BW_i \cdot AT \cdot 365 \text{ d/y}}{EF_o \cdot ED_o \left[ \left( \frac{IRS_o \cdot CSF_o}{10^6 \text{ mg/kg}} \right) + \left( \frac{SA_i \cdot SL \cdot ABS}{10^6 \text{ mg/kg}} \right) + \left( \frac{IRA_i \cdot CSF_i}{VF^a} \right) \right]}$$

**Equation 3-4: Direct Exposures to Noncarcinogenic Contaminants in Industrial Soil**

$$C(\text{mg/kg}) = \frac{THQ \cdot BW_i \cdot ED_o \cdot 365 \text{ d/y}}{EF_o \cdot ED_o \left[ \left( \frac{1}{RfD_o} \cdot \frac{IRS_o}{10^6 \text{ mg/kg}} \right) + \left( \frac{1}{RfD_o} \cdot \frac{SA_i \cdot SL \cdot ABS}{10^6 \text{ mg/kg}} \right) + \left( \frac{1}{RfD_i} \cdot \frac{IRA_i}{VF^a} \right) \right]}$$

**Footnote:**

\*Use VF for volatile chemicals (defined as having a Henry's Law Constant [atm-m<sup>3</sup>/mol] greater than 10<sup>-6</sup> and a molecular weight less than 200 grams/mol) or PEF for non-volatile chemicals.



Tap Water Equations:

**Equation 3-5: Ingestion and Inhalation Exposures to Carcinogenic Contaminants in Tap Water**

$$C(\text{ug/L}) = \frac{TR \cdot AT \cdot 365 \text{d/y} \cdot 1000 \text{ug/mg}}{EF_r [ (IFW_{adj} \cdot CSF_o) + (VF_v \cdot InhF_{adj} \cdot CSF_1) ]}$$

**Equation 3-6: Ingestion and Inhalation Exposures to Noncarcinogenic Contaminants in Tap Water**

$$C(\text{ug/L}) = \frac{THQ \cdot BW_a \cdot ED_r \cdot 365 \text{d/y} \cdot 1000 \text{ug/mg}}{EF_r \cdot ED_r [ (\frac{IRW_a}{RfD_o}) + (\frac{VF_v \cdot IRA_a}{RfD_1}) ]}$$

Air Equations:

**Equation 3-7: Inhalation Exposures to Carcinogenic Contaminants in Air**

$$C(\text{ug/m}^3) = \frac{TR \cdot AT \cdot 365 \text{d/y} \cdot 1000 \text{ug/mg}}{EF_r \cdot InhF_{adj} \cdot CSF_1}$$

**Equation 3-8: Inhalation Exposures to Carcinogenic Contaminants in Air**

$$C(\text{ug/m}^3) = \frac{THQ \cdot RfD_1 \cdot BW_a \cdot ED_r \cdot 365 \text{d/y} \cdot 1000 \text{ug/mg}}{EF_r \cdot ED_r \cdot IRA_a}$$

## SOIL-TO-AIR VOLATILIZATION FACTOR (VF)

Equation 3-9: Derivation of the Volatilization Factor air dispersion term

$$VF(m^3/kg) = \frac{(LS \cdot V \cdot DH)}{A} \cdot \frac{(3.14 \cdot \alpha \cdot T)^{1/2}}{(2 \cdot D_{ef} \cdot P_a \cdot K_{as} \cdot 10^{-3} kg/g)} \quad \text{--- emission rate term (inverted)}$$

where:

$$\alpha = \frac{D_{ef} \cdot P_a}{P_a + [(\rho_s)(1 - P_a)/K_{as}]}$$

Parameter	Definition (units)	Default
VF	Volatilization factor (m <sup>3</sup> /kg)	-
LS	Length of side of contaminated area (m)	45
V	Windspeed in mixing zone (m/s)	2.25
DH	Diffusion height (m)	2
A	Area of contamination (cm <sup>2</sup> )	20,250,000
D <sub>ef</sub>	Effective diffusivity (cm <sup>2</sup> /s)	D <sub>i</sub> (P <sub>a</sub> <sup>1.25</sup> /P <sub>i</sub> <sup>1.25</sup> )
P <sub>a</sub>	Air filled soil porosity (unitless)	P <sub>i</sub> - θB
P <sub>i</sub>	Total soil porosity (unitless)	1 - (B/ρ <sub>s</sub> )
θ	Soil moisture content (cm <sup>3</sup> -water/g-soil)	0.1
B	Soil bulk density (g/cm <sup>3</sup> )	1.5
ρ <sub>s</sub>	True soil density or particle density (g/cm <sup>3</sup> )	2.65
K <sub>as</sub>	Soil-air partition coefficient (g-soil/cm <sup>3</sup> -air)	(H/K <sub>ow</sub> ) x 41 (41 is a conversion factor)
T	Exposure interval (s)	7.9 x 10 <sup>8</sup>
D <sub>i</sub>	Diffusivity in air (cm <sup>2</sup> /s)	Chemical-specific
H	Henry's Law constant (atm-m <sup>3</sup> /mol)	Chemical-specific
K <sub>ow</sub>	Soil-water partition coefficient (cm <sup>3</sup> /g)	K <sub>ow</sub> x OC
k <sub>oc</sub>	Organic carbon partition coefficient (cm <sup>3</sup> /g)	Chemical-specific
OC	Organic carbon content of soil (fraction)	0.02

## **APPENDIX F**

### **TIER 1 SOIL ACTION LEVELS GENERATED FROM GROUNDWATER-IMPACT, CONTAMINANT SATURATION, AND DIRECT-EXPOSURE MODELS**

TABLE 1a. Tier 1, SESOIL-generated soil action levels for groundwater-protection concerns at release sites that threaten groundwater that is a source of drinking water. Standard-rainfall models.

DRINKING WATER SOURCE THREATENED - RAINFALL $\leq 200\text{cm/year}$							
Contaminant	Groundwater (mg/l)	Soil (mg/kg): *Depth to Groundwater (meters)					
		* 5m	$\geq 10\text{m}$	$\geq 20\text{m}$	$\geq 30\text{m}$	$\geq 40\text{m}$	$\geq 50\text{m}$
Benzene	0.005	0.005	0.03	0.24	1.1	4.3	14
Toluene	1.0	16.1	120	170sat			
Ethylbenzene	(0.14)	0.50	1.5	13	46	170	200sat
Xylene	10	23	59sat				
Benzo(a)pyrene	0.0002	3.4sat					
Acenaphthene	(0.32)	18sat					
Fluoranthene	(0.013)	11sat					
Naphthalene	0.24	41sat					
PCE	0.005	0.29	2.3	31	130sat		
1,1 DCE	0.046	490sat					
Vinyl Chloride	0.002	5,900sat					
TCE	0.005	0.01	0.04	0.26	0.89	2.2	4.5
1,1,1 TCA	0.20	0.10	0.18	0.53	1.0	1.5	2.4

Additional SESOIL results: Benzene  $\geq 75\text{m}$ : 147mg/kg,  $\geq 100\text{m}$ : 210sat  
TCE  $\geq 70\text{m}$ : 9.9mg/kg  
1,1,1 TCA  $\geq 75\text{m}$ : 6.6mg/kg,  $\geq 100\text{m}$ : 13mg/kg

TABLE 1b. Tier 1, SESOIL-generated soil action levels for groundwater protection concerns at release sites that do not threaten groundwater that is a source of drinking water. Standard-rainfall models.

DRINKING WATER SOURCE NOT THREATENED - RAINFALL $\leq 200\text{cm/year}$							
Contaminant	Groundwater (mg/l)	Soil (mg/kg): *Depth to Groundwater (meters)					
		* 5m	$\geq 10\text{m}$	$\geq 20\text{m}$	$\geq 30\text{m}$	$\geq 40\text{m}$	$\geq 50\text{m}$
Benzene	1.7	1.7	9.2	82	210sat		
Toluene	2.1	34	170sat				
Ethylbenzene	0.14	0.50	1.5	13	46	170	200sat
Xylene	[10]	23	59sat				
Benzo(a)pyrene	[0.0002]	3.4sat					
Acenaphthene	0.32	18sat					
Fluoranthene	0.013	11sat					
Naphthalene	0.77	41sat					
PCE	0.145	8.4	67	130sat			
1,1 DCE	3.9	490sat					
Vinyl Chloride	[0.002]	5,900sat					
TCE	0.70	1.5	5.7	36	125	210sat	
1,1,1 TCA	6.0	3.0	5.4	16	31	47	72

Additional SESOIL results: 1,1,1 TCA  $\geq 75\text{m}$ : 170sat

TABLE 1c. Tier 1, SESOIL-generated soil action levels for groundwater protections concerns at release sites that threaten groundwater that is a source of drinking water. High-rainfall models.

DRINKING WATER SOURCE THREATENED - RAINFALL $\geq 200\text{cm/year}$							
Contaminant	Groundwater (mg/l)	Soil (mg/kg): *Depth to Groundwater (meters)					
		* $\leq 5\text{m}$	$\geq 10\text{m}$	$\geq 20\text{m}$	$\geq 30\text{m}$	$\geq 40\text{m}$	$\geq 50\text{m}$
Benzene	0.005	0.002	0.006	0.03	0.08	0.20	0.42
Toluene	1.0	2.6	13	143	170sat		
Ethylbenzene	(0.14)	0.13	0.35	1.6	4.5	9.9	19
Xylene	10	8.1	18	59sat			
Benzo(a)pyrene	0.0002	3.4sat					
Acenaphthene	(0.32)	18sat					
Fluoranthene	(0.013)	11sat					
Naphthalene	0.24	41sat					
PCE	0.005	0.04	0.15	0.88	2.6	6.2	
1,1 DCE	0.046	490					
Vinyl Chloride	0.002	5,900sat					
TCE	0.005	0.004	0.008	0.03	0.08	0.15	0.27
1,1,1 TCA	0.20	0.06	0.13	0.22	0.44	0.58	0.83

1. Additional SESOIL results: Benzene  $\geq 75\text{m}$ : 2.7mg/kg,  $\geq 100\text{m}$ : 12mg/kg  
Ethylbenzene  $\geq 75\text{m}$ : 80mg/kg,  $\geq 100\text{m}$ : 200sat  
TCE  $\geq 75\text{m}$ : 0.68mg/kg,  $\geq 100\text{m}$ : 1.5mg/kg  
1,1,1 TCA -  $\geq 75\text{m}$ : 1.7mg/kg,  $\geq 100\text{m}$ : 3.1mg/kg

TABLE 1d. Tier 1, SESOIL-generated soil action levels for groundwater protection concerns at release sites that do not threaten groundwater that is a source of drinking water. High-rainfall models.

DRINKING WATER SOURCE NOT THREATENED - RAINFALL $\geq 200\text{cm/year}$							
Contaminant	Groundwater (mg/l)	Soil (mg/kg): *Depth to Groundwater (meters)					
		* *5	$\geq 10\text{m}$	$\geq 20\text{m}$	$\geq 30\text{m}$	$\geq 40\text{m}$	$\geq 50\text{m}$
Benzene	1.7	0.64	1.9	9.7	28	69	140
Toluene	2.1	2.6	13	143	170sat		
Ethylbenzene	0.14	0.13	0.35	1.6	4.5	9.9	19
Xylene	[10]	8.1	18	59sat			
Benzo(a)pyrene	[0.0002]	3.4sat					
Acenaphthene	0.32	18sat					
Fluoranthene	0.013	11sat					
Naphthalene	0.77	41sat					
PCE	0.145	1.2	4.4	26	75	130sat	
1,1 DCE	3.9	490					
Vinyl Chloride	[0.002]	5,900sat					
TCE	0.70	0.56	1.1	4.9	12	22	38
1,1,1 TCA	6.0	1.9	3.8	6.6	13	17	25

1. Additional SESOIL results: Benzene  $\geq 75\text{m}$ : 210sat  
Ethylbenzene  $\geq 75\text{m}$ : 80mg/kg,  $\geq 100\text{m}$ : 200sat  
TCE  $\geq 75\text{m}$ : 95mg/kg,  $\geq 100\text{m}$ : 210sat  
1,1,1 TCA  $\geq 75\text{m}$ : 52mg/kg,  $\geq 100\text{m}$ : 93mg/kg

TABLE 1 (cont.). Tier 1, SESOIL-generated soil action levels for groundwater protection concerns: Notes

NOTES

sat: Contaminant saturation limit. Groundwater-protection SAL cannot exceed contaminant saturation limit.

\*: depth to groundwater as measured from base of impacted interval

\* \*: Used in development of Tier 1 lookup tables (see text).

() Same as surface water; surface water standard more stringent than drinking water standard.

[] Same as drinking water; surface water standards not set.

1. Soil action levels presented assume a two-meter thick interval of impacted soil.

2. Dilution of leachate in groundwater not taken into account. Refer to Tier 2 discussion (Chapter 2) for modification of soil action levels presented in this table with respect to a site specific dilution attenuation factor (DAF).

SESOIL MODEL (see text)

Climate data: Standard rainfall models: Ahuimanu Loop station data adjusted to 200cm annual rainfall.

High rainfall models: Honomu Mauka station data adjusted to 400cm annual rainfall.

Geologic model: Sand or very permeable saprolite/soil overlying fractured, porous basalt.



TABLE 2. Tier 1 contaminant soil saturation levels.

Contaminant	<sup>1</sup> Contaminant Saturation Soil Action Level (mg/kg)
Benzene	210
Toluene	170
Ethylbenzene	200
Xylene	59
Benzo(a)pyrene	3.4
Acenaphthene	18
Fluoranthene	11
Naphthalene	41
PCE	130
1,1 DCE	490
Vinyl Chloride	5,900
TCE	210
1,1,1 TCA	170
TPH-residual fuels	<sup>2</sup> 5,000
TPH-middle distillates	<sup>2</sup> 5,000
TPH-gasolines	<sup>2</sup> 2,000

N/A - not applicable

1. Soil saturation levels generated using SESOIL unless otherwise noted. Saturation levels presented for common petroleum constituents address potential mobilization of the free product mixture as a whole rather than a specific contaminant. See text.
2. Saturation/nuisance levels set by DOH (HIDOH 1995d).

TABLE 3. Tier 1 direct-exposure soil action levels.

Contaminant	<sup>1</sup> Direct-Exposure Soil Action Level (mg/kg)
Benzene	5.3
Toluene	4100
Ethylbenzene	4600
Xylene	10,000
Benzo(a)pyrene	<sup>2</sup> 1.0
Acenaphthene	2500
Fluoranthene	2500
Naphthalene	1200
PCE	5.0
1,1 DCE	0.47
Vinyl Chloride	0.18
TCE	20
1,1,1 TCA	4300
Polychlorinated- biphenyls (PCBs)	<sup>2</sup> 1.0
Lead (total)	400
Cadmium (total)	38
TPH-residual fuels	N/A
TPH-middle distillates	N/A
TPH-gasolines	N/A

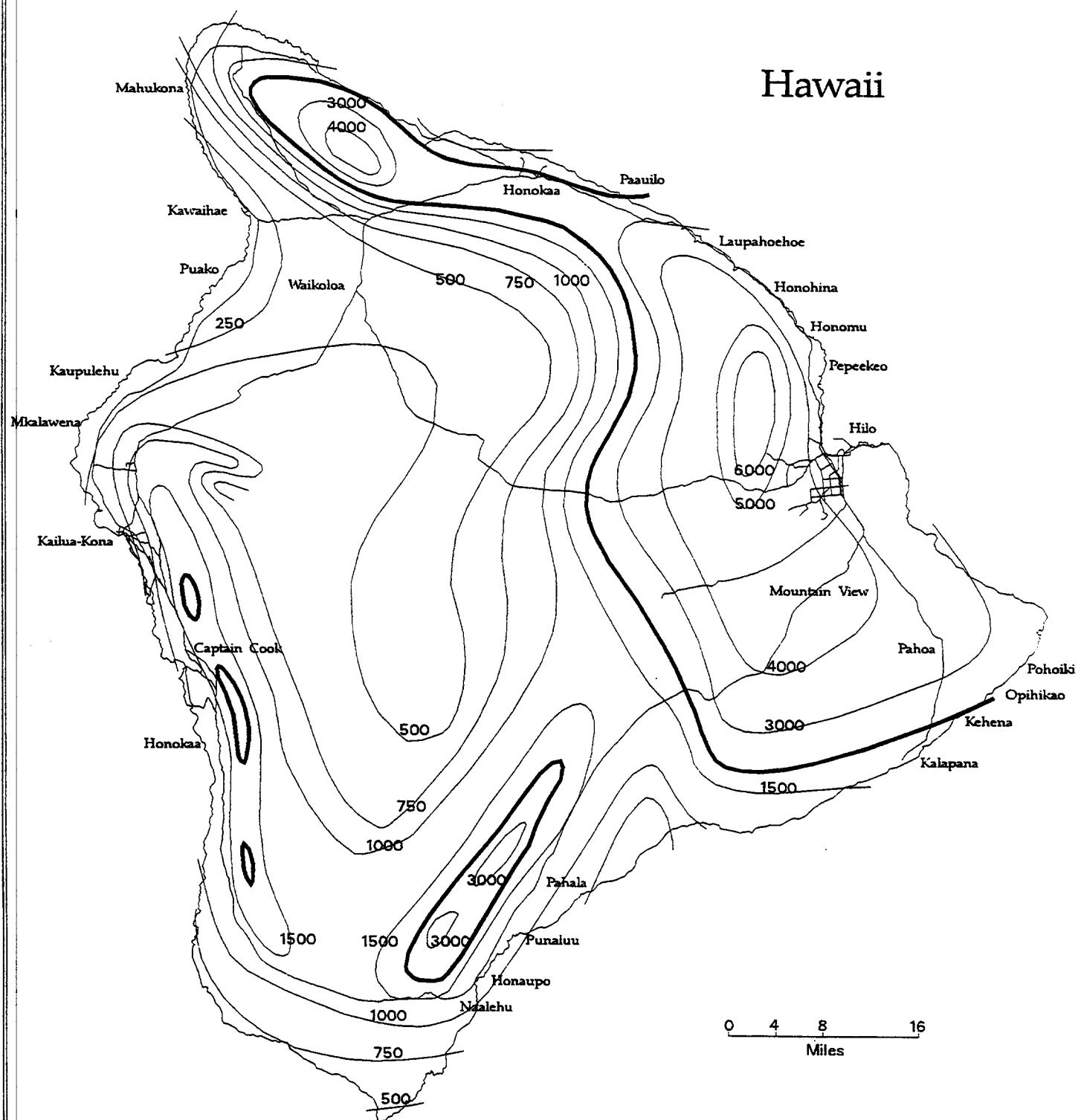
N/A - not applicable

1. Direct-exposure soil action levels generated by use of risk-based, quantitative models unless otherwise noted (rounded off to two significant digits.) SALs set to meet a  $10^{-6}$  risk or hazard quotient of 1. See text.
2. Direct-exposure soil action level generated independently by DOH (HIDOH, 1992).

## **APPENDIX G**

### **RAINFALL ISOHYET MAPS FOR THE MAJOR ISLANDS OF HAWAI'I**

# Hawaii



Island of Hawaii - Median Rainfall Isohyets

- 2000 mm
- Major Roads



Source: DOWALD

# Island of Kauai Median Rainfall Isohyets

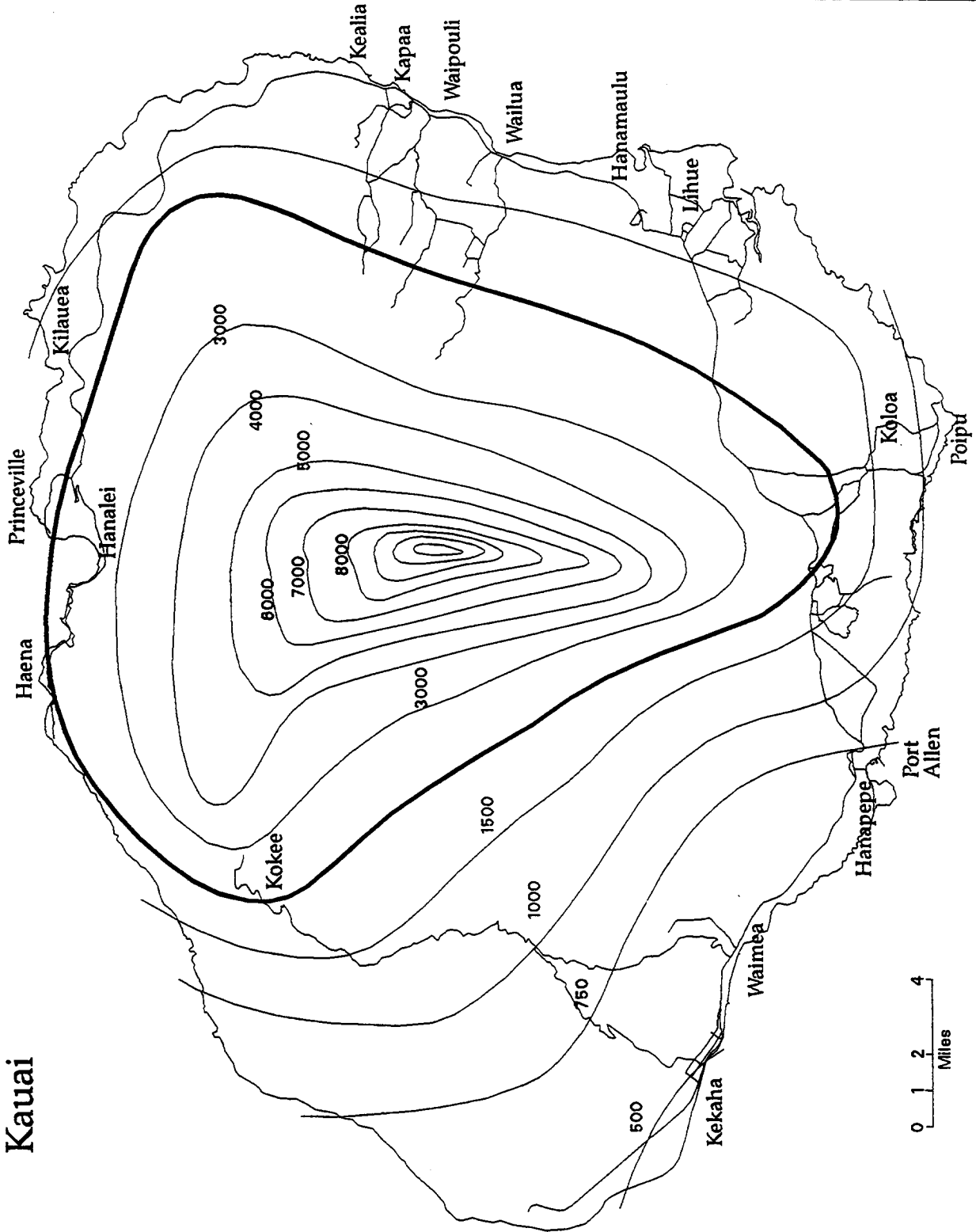
— 2000 mm

~ Major Roads

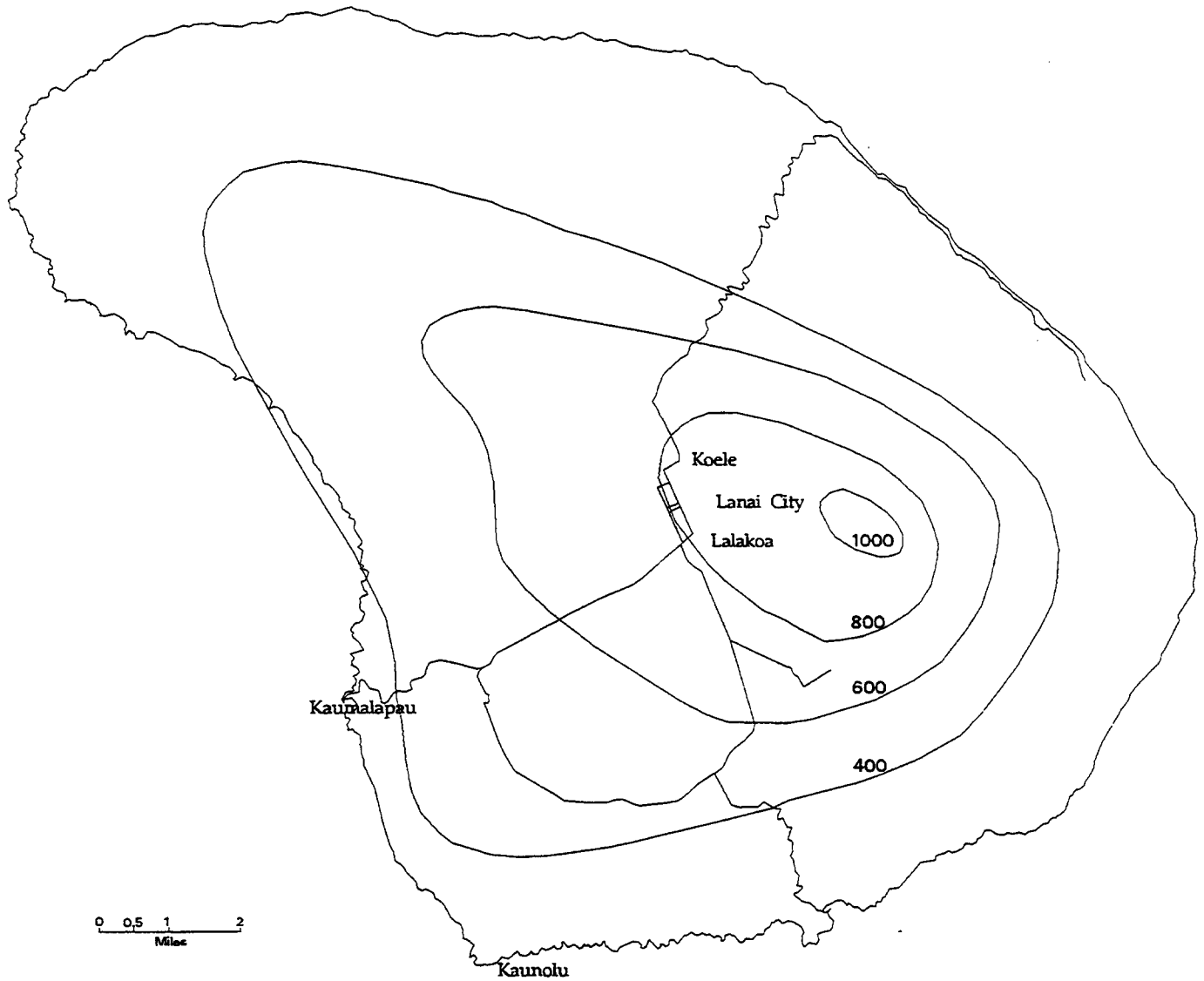
Source: DOWALD



Kauai



# Lanai



Island of Lanai - Median Rainfall Isohyets

Major Roads



Source: DOWALD

# Island of Maui Median Rainfall Isohyets

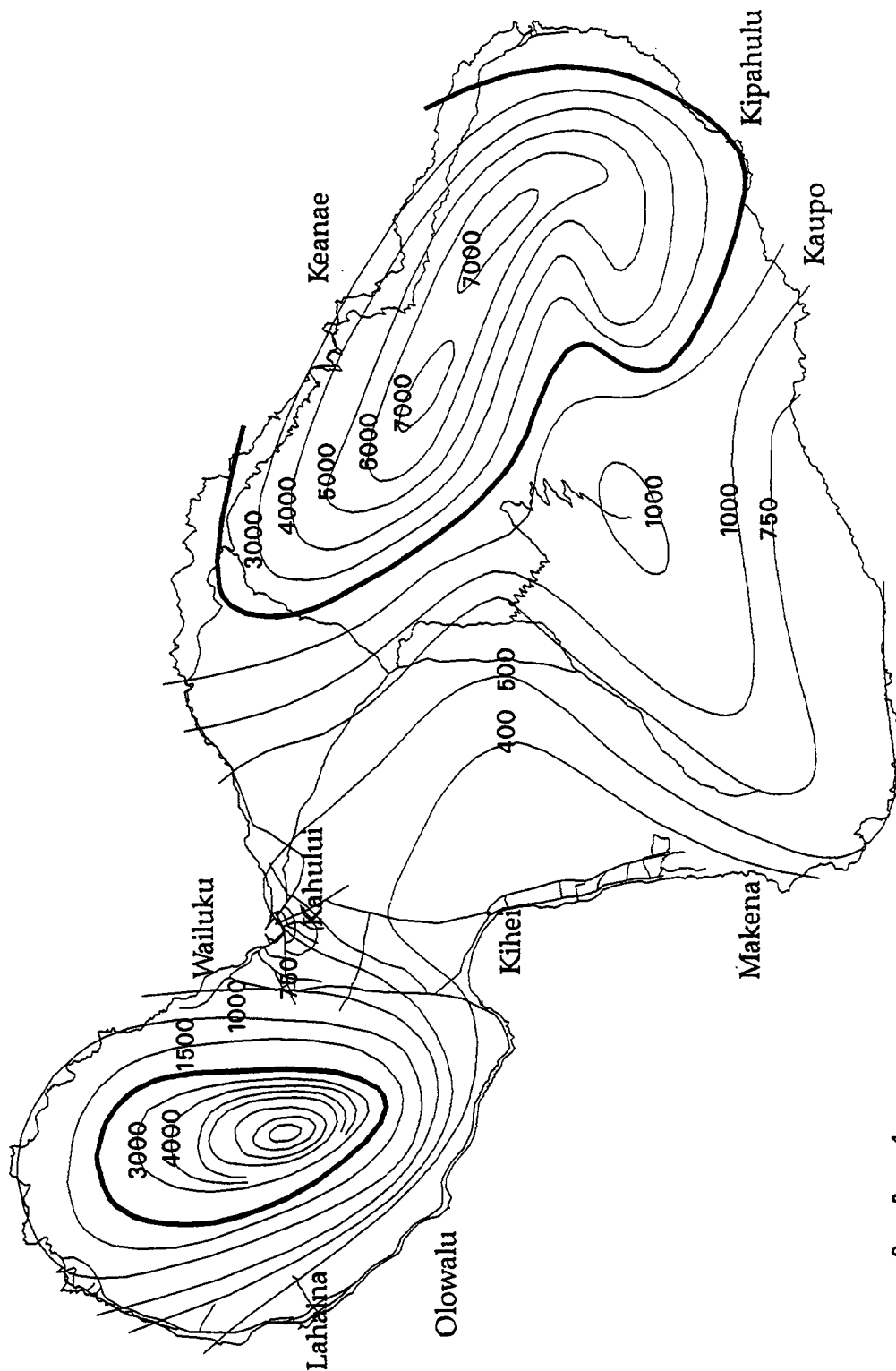
— 2000 mm

∨ Major Roads

Source: DOWALD



## Maui



0 2 4  
Miles

# Island of Molokai Median Rainfall Isohyets

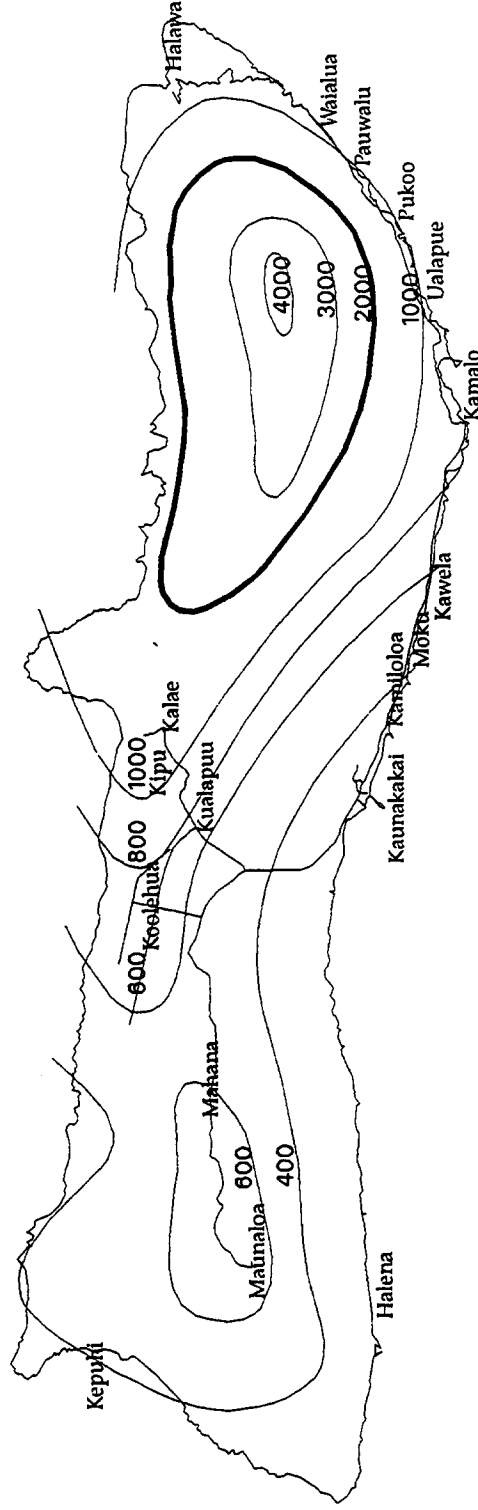
— 2000 mm

∨ Major Roads

Source: DOWALD



## Molokai



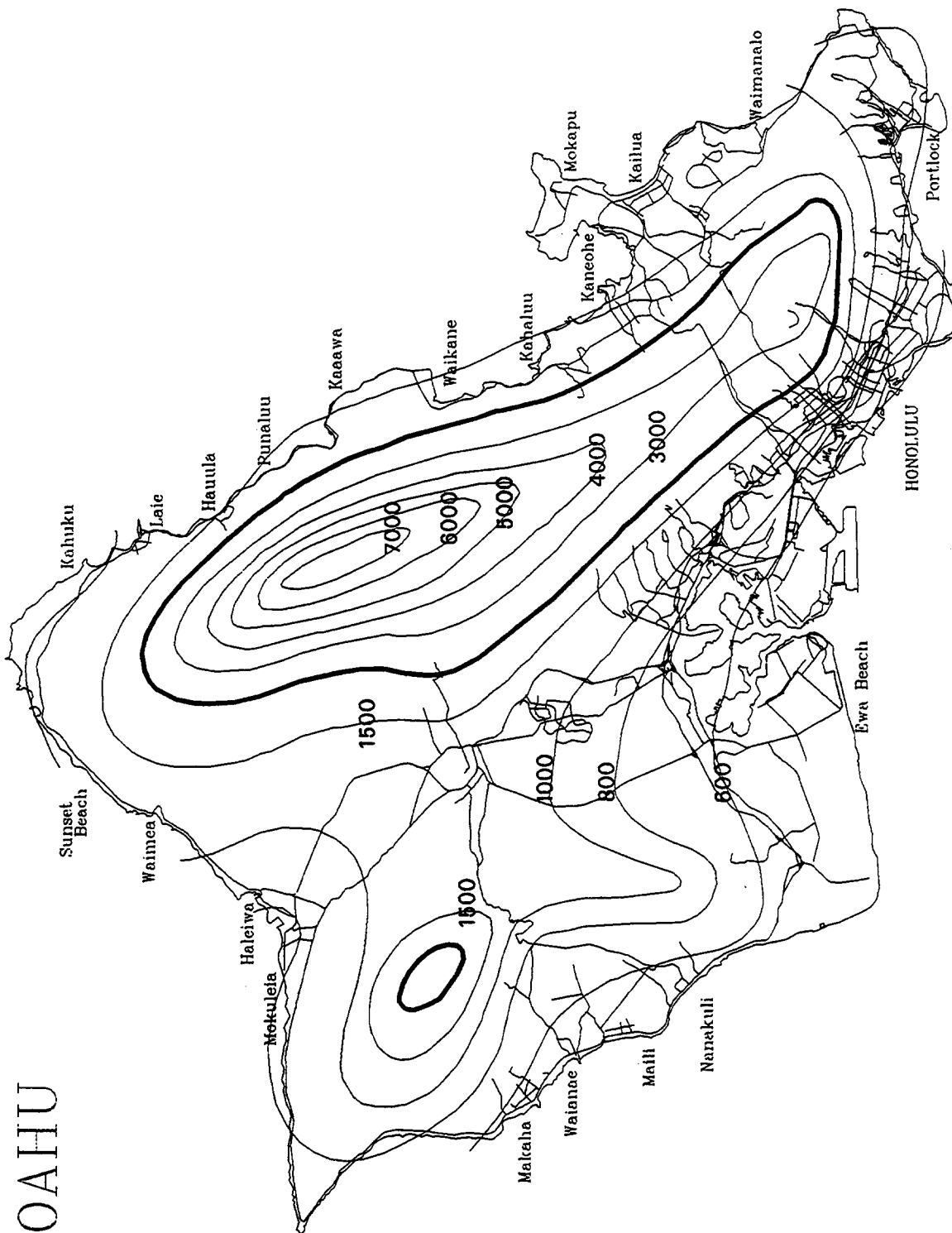
0 1 2 4  
Miles



# Island of Oahu Median Rainfall Isohyets

— 2000 mm  
 \ Major Roads

Source: DOWALD



0 2 4  
Miles

OAHU

## **APPENDIX H**

### **EXAMPLE PRINTOUT FROM QUIKSOIL SPREADSHEET**

## TIER II SIMPLIFIED MODEL FOR GROUNDWATER-PROTECTION SOIL ACTION LEVELS

QUIKSOIL Version: November 1995

State of Hawai'i

Department of Health

Environmental Management Division

**Calculates Tier 2 soil action level (SAL) for protection against adverse leachate impact on groundwater.**

**Does not incorporate vadose-zone fate and transport of leachate. (SESOIL computer application should be used for highly volatile or biodegradable contaminants or for sites where the base of the impacted soils is more than 10 meters from groundwater. See text.)**

**Does not address dilution of leachate on mixing with groundwater. SALs generated using this spreadsheet should be multiplied by the site dilution attenuation factor to calculate the final Tier 2 groundwater-protection SAL for the site (refer to DAF spreadsheet).**

- STEPS.**
1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.
  2. \*Input site data. Use default values where site-specific data are not available.
  3. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)
  4. Spreadsheet generates leachate-impact SAL for site (see accompanying document).
  5. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

\*Site-specific input data must be supported in text of site investigation report(s).

CONTAMINANT: Chlordane

<sup>1</sup>Groundwater Protection SAL: (mg/kg): 0.051

Site Data	DEFAULT	INPUT	Chemical Data (see below)	Chlordane
<sup>2</sup> Target Leachate Conc. mg/l	N/A	0.002	Kh atm m <sup>3</sup> /mole	4.80E-05
Soil density (g/cm3)	1.50	1.50	Kh dimensionless	0.0019
Particle dns. (g/cm3)	2.65	2.65	Koc ml/g	38019
Fraction air-filled porosity	0.65	0.65		
<sup>3</sup> Fraction organic carbon in so	0.001	0.001		

SITE NAME:

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

<b>Calculations:</b>	
Soil porosity - total	0.43
Soil porosity - air-filled	0.28
Soil porosity - water-filled	0.15

**Notes:**

1. Equation modified after ASTM. 1994. *Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. Designation ES 38-94. Philadelphia, Pennsylvania. (Table X2.1. Dilution factor omitted.)
2. Target concentration of contaminant in leachate at the point the leachate passes into groundwater.  
Target leachate concentration should equal contaminant MCL or surface water standard, as determined by the location of the site (refer to *Determination of Groundwater Utility at Leaking Underground Storage Tank Sites (September 19, 1995)*: Hawai'i Department of Health, Environmental Management Division).
3. For soils with mixtures of contaminants, assume that no more than 10% of the total organic carbon (foc) is available for adsorption of any one contaminant.

**Reference:**

HIDOH. 1995. *Risk-Based Corrective Action And Decision Making At Sites With Contaminated Soil And Groundwater*: Hawai'i Department of Health, Environmental Management Division.

## **APPENDIX I**

### **EXAMPLE TIER 2 EVALUATION RESULTS**

## EXAMPLE 1

EXAMPLE 1. Inland area over basal, unconfined, drinking water groundwater system in basalt. Base of impacted soil  $\geq$  10m above top of groundwater. Moderate rainfall (150cm/year). Impacted soil area 30m long by 30m wide and 2m thick. Groundwater gradient assumed to be 0.001.

<sup>1</sup> Contaminant	<sup>2</sup> SESOIL SAL (mg/kg)	<sup>3</sup> Site DAF	<sup>4</sup> Groundwater Protection SAL (mg/kg)	<sup>5</sup> Direct-Exposure SAL (mg/kg)	<sup>6</sup> SAL chosen for site (mg/kg)
Benzene	0.027	2.5	0.07	6.8	0.07
Toluene	124	2.5	<sup>4</sup> 170sat	5340	170
PCE	2.3	2.5	5.8	5.8	5.8

1. The contaminants noted exceeded Tier 1 soil action levels (SALs) at the example site.
2. Default Tier 1 SESOIL SALs for leachate concerns used rather than re-running the computer application to generate site-specific Tier 2 SALs (refer to Appendix F, Table 1a).
3. Site dilution attenuation factor (DAF) as calculated using DAF spreadsheet (see attached spreadsheet).
4. Site SALs for groundwater-protection concerns calculated by multiplying the SESOIL SAL times the leachate dilution attenuation factor. Maximum groundwater-protection SAL is the contaminants theoretical saturation limit ("sat", refer to Appendix F, Table 2).
5. Contaminant direct-exposure SALs as calculated using DETIER2 spreadsheet (see attached spreadsheet).
6. SAL chosen for site reflects the contaminant pathway of most concern.

## TIER II: SITE-SPECIFIC LEACHATE DILUTION ATTENUATION FACTOR (DAF)

DAF Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

**Calculates dilution attenuation factor for dilution of leachate in groundwater.**

**Applies to basal, unconfined groundwater (aquifer) systems only (refer to Mink and Lau, 1990).**

**For high-level aquifers, input a groundwater gradient of 0.001 unless available data suggest otherwise.**

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. \*Input site data. Use default values where site-specific data are not available.  
3. Spreadsheet generates leachate Dilution Attenuation Factor for site.  
4. Complete information at bottom of this page.

\*Site-specific input data must be supported in text of site investigation report(s).

SITE VARIABLES		DEFAULT	INPUT	Default hydraulic conductivities (m/d)	
<sup>1</sup> Hydraulic Conductivity (m/d):	K	see table	10.0	basalt (all types):	10
Aquifer Thickness (m):	d <sub>a</sub>	10	10	sandy/coralline sediments:	10
Effective Porosity (fraction):	n <sub>eff</sub>	0.30	0.30	saprolite/silty sediments:	2.0
<sup>2</sup> Average site groundwater elevation (m)	E <sub>gw</sub>	site-specific	n/a	clayey sediments or soils:	0.1
<sup>3</sup> Distance to ocean (m)	D	site-specific	n/a		
<sup>4</sup> Source Length (m):	L	site-specific	30		
<sup>5</sup> Precipitation (cm/yr):	p	200	150		
<sup>6</sup> Fraction groundwater recharge:	gw <sub>r</sub>	0.36	0.36		

CALCULATIONS:		
<sup>8</sup> Infiltration Rate (m/y)	I	0.54
<sup>9</sup> Regional Hydraulic Gradient (m/m):	h	0.001
<sup>10</sup> Groundwater Velocity (m/y)	V <sub>s</sub>	12.17
<sup>11</sup> Mixing Zone Depth (m)	d <sub>M</sub>	6.8
<sup>12</sup> Dilution Attenuation Factor:	DAF	2.5

SITE NAME: EXAMPLE #1

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):



NOTES:

1. Hydraulic conductivity of formation carrying groundwater.
2. Approximate, average groundwater elevation at release site. Input N/A for high-level groundwater systems or if no information is available. (See also note 8.)
3. Distance from release site to coastline as measured from a point representative of the average groundwater elevation for the release site. Input N/A for high-level groundwater systems or if N/A was input for groundwater elevation (See also note 8.)
4. Length of contaminated soil source as measured parallel to groundwater flow.
5. Refer to annual rainfall maps included in Tier 2 report. Input rainfall as meters per year. Reference map used in report.
6. Default recharge is 36% of total rainfall (average for Oahu; refer to Atlas of Hawai'i, 1983, for other islands).
7. Equations modified after ASTM RBCA guidance (ES-38, 1994). See text.
8. Infiltration rate = annual precipitation x fraction groundwater recharge.
9. Groundwater gradient at site. Use approximate regional gradient unless otherwise directed or approved by DOH. Spreadsheet generates default regional gradient based in input average groundwater elevation at site and distance to ocean. For high-level groundwater systems or sites where the information needed to approximate groundwater gradient is uncertain or not available, input a gradient of 0.001 unless demonstrated by other data.
10. Groundwater velocity calculated as seepage velocity.
11. Mixing zone depth. Spreadsheet limits maximum mixing depth to input aquifer thickness.
12. DAF = ratio of contaminant concentration in soil leachate to concentration after mixing of leachate in groundwater. To generate a Tier 2 soil action levels for groundwater impact concerns, multiply the Tier 1 or Tier 2, SESOIL-generated soil action level by the DAF calculated for the site. DAF most sensitive to hydraulic conductivity, hydraulic gradient, and rainfall/infiltration rate.

References:

- ASTM. 1994. Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (July, 1994): American Association for Testing and Materials (ASTM), Designation ES 38-94.
- HIDOH. 1995. *Risk-Based Corrective Action And Decision Making At Sites With Contaminated Soil And Groundwater*: Hawai'i Department of Health, Environmental Management Division.
- Mink, J.F. and Lau, S.L. 1990. Aquifer Identification and Classification for Oahu: Groundwater Protection Strategy for Hawai'i: Water Resources Research Center, University of Hawai'i at Manoa, Technical Report No. 179.

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT: Benzene	
Carcinogen Soil Action Level (mg/kg):	6.78
Non-carcinogen Soil Action Level (mg/kg):	N/A

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Benzene
MW		78
Sol	mg/l	1800
Kh	atm m <sup>3</sup> /mole	0.0055
Kh	dimensionless	0.2214
Di-air	cm <sup>2</sup> /sec	0.088
Koc	ml/g	65
CSFo	1/(mg/kg-d)	2.90E-02
CSFi	1/(mg/kg-d)	2.90E-02
RfDo	mg/kg-d	
RfDi	mg/kg-d	

SITE NAME:

SITE ADDRESS:

DOH ID NO. \_\_\_\_\_

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

Human Receptor Data (fixed)			INPUT
25% surface area - adults	SAa	cm <sup>2</sup>	5000
25% surface area - children	SAc	cm <sup>2</sup>	2000
Adherence factor	AF	mg/cm <sup>2</sup>	0.2
Skin absorption factor	ABS	unitless	0.10
Inhalation Rate - adults	IRAa	m <sup>3</sup> /d	20
Inhalation Rate - children	IRAc	m <sup>3</sup> /d	10
Soil ingestion rate - adults	IRSA	mg/d	100
Soil ingestion rate - children	IRSc	mg/d	200
Exposure time - residents	ETr	h/d	24
Exposure frequency - residents	EFr	d/y	350
Exposure duration - residents total	EDr	hrs	30
Exposure duration - children	EDc	hrs	6
Body weight - adult	BWa	kg	70
Body weight - child	BWc	kg	15
Averaging time (years)	AT	hrs	70
Days/year conversion		d/yr	365
Target Risk ( x 10 <sup>-6</sup> )	R		1
Target Hazard Quotient	HQ		1

<b>Other variables (fixed)</b>			
Surface diffusion height	DH	m	2
<b><sup>4</sup>Calculations</b>			
<b>Various:</b>			
Side perpendicular to wind (assumed = area <sup>0.5</sup> )	LS	m	30
Soil porosity	Pt		0.43
Soil air-filled porosity	Pa		0.28
Soil-water partition coeff.	Kd	cm <sup>3</sup> /g	1.30E-01
<sup>5</sup> Air dispersion factor - outdoor	ER	m <sup>3</sup> /sec	1.50E+02
Ingestion exposure factor	IFS	mg-yr/kg-d	114
Skin contact exposure factor	SFS	mg-yr/kg-d	503
Inhalation exposure factor	InhF	mg <sup>3</sup> -yr/kg-d	11
<b>Impacted-Soil Emissions:</b>			
Effective diffusivity - soil to air	Dei <sub>sa</sub>	cm <sup>2</sup> /sec	7.06E-03
<sup>6</sup> Volatilization factor - modified PRG	VF <sub>prgr</sub>	m <sup>3</sup> /kg	4.60E+03
<sup>7</sup> Volatilization factor - mass balanced	VF <sub>mbr</sub>	m <sup>3</sup> /kg	5.26E+04
<sup>8</sup> Volatilization factor site scenario	VF <sub>res</sub>	m <sup>3</sup> /kg	5.26E+04
<sup>9</sup> Particulate emission factor	PEF	m <sup>3</sup> /kg	2.42E+06
<sup>10</sup> Soil action level (carcinogen) - residential	SAL <sub>cr</sub>	mg/kg	6.78E+00
<sup>11</sup> Soil action level (non-carcinogen) - residential	SAL <sub>ncr</sub>	mg/kg	0.00E+00
<b>Other:</b>			
Mass impacted soil		g	2.70E+06

#### NOTES:

1. Use default physio-chemical and toxicity data provided in EPA Region IX PRGs (from IRIS data base), First Half, 1995, or as otherwise directed or approved by DOH.
2. Total areal extent of soil contaminated above Tier 1 soil action levels.
3. For soils contaminated with a mixture of contaminants (e.g., petroleum), assume a default foc of 0.002 or a maximum of 10% of the measured total soil foc. For soils contaminated with a pure product, assume a default foc of 0.02 or the measured total soil foc.
4. Calculations based on modified equations presented in EPA Region IX PRGs (USEPA, 1995, see text).
5. ER (or "dispersion factor") for outdoor air calculated using  $ER = LS \times V \times DH$ . (Refer to California Preliminary Endangerment Assessment Guidance Manual, pg. B-3. ER term Incorporated into August 1, 1994, EPA Region IX PRGs "Volatilization Factor" equation 3-9. Also incorporated into ASTM RBCA guidance, Table X2.1. Air exchange rate/area term in 1994 PRGs replaced with default "Q/C" value in 1995 PRG model. See also Note 6.)
6. Volatilization factor calculated using modification of equation 4-9 in EPA Region IX PRGs, First Half, 1995. PRG equation is equivalent to "air dispersion term/(emission rate/soil concentration)" as can be generated using equations presented in Fig. 2-7 (emission rate) and on pg B-3 (includes air exchange rate) in California Preliminary Endangerment Assessment Guidance Manual. (See also notes 4 & 5.)
7. Mass-balanced volatilization factor. Takes into account the thickness of soil impacted with volatile contaminants. (Not applicable for semi-volatile and non-volatile contaminants.) Calculated by dividing the total contaminant mass by the total exposure duration. Reflects the maximum, average emission rate required for the source to be completely exhausted at the end of the input exposure duration. (i.e., Worst-case scenario. All of the contaminant is emitted from the soil during the exposure period.)
8. Volatilization factor used for site model (see text).
9. Particulate emission factor calculated using equation 4-11 from EPA Region IX PRGs, First Half, 1995, but substituting air exchange rate/area (ER/A) for the term Q/C. (Refer to notes 5 & 6.) ASTM default particulate emission rate is  $6.9E-13 \text{ kg/m}^2\text{-s}$ .
10. Calculated using equation 4-1 from EPA Region IX PRGs, First Half, 1995.
11. Calculated using equation 4-2 from EPA Region IX PRGs, First Half, 1995.

#### REFERENCES:

- ASTM. 1994. *Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. Designation ES 38-94. Philadelphia, Pennsylvania.
- California EPA. 1994. *Preliminary Endangerment Assessment Guidance Manual*. Department of Toxic Substances Control, Sacramento, California.
- HIDOH. 1995. *Risk-Based Corrective Action And Decision Making At Sites With Contaminated Soil And Groundwater*: Hawai'i Department of Health, Environmental Management Division.
- U.S. EPA. 1994. *Region IX Preliminary Remediation Goals (PRGs) Second Half, 1994*. Technical Support Section, San Francisco, California.
- U.S. EPA. 1995. *Region IX Preliminary Remediation Goals (PRGs) First Half, 1995*. Technical Support Section, San Francisco, California.

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:	
Toluene	
Carcinogen Soil Action Level (mg/kg):	N/A
Non-carcinogen Soil Action Level (mg/kg):	5339.54

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Toluene
MW		92
Sol	mg/l	520
Kh	atm m <sup>3</sup> /mole	0.0066
Kh	dimensionless	0.2656
Di-air	cm <sup>2</sup> /sec	0.078
Koc	ml/g	260
CSFo	1/(mg/kg-d)	
CSFi	1/(mg/kg-d)	
RfDo	mg/kg-d	2.00E-01
RfDi	mg/kg-d	1.10E-01

SITE NAME: EXAMPLE #1

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:		PCE
Carcinogen Soil Action Level (mg/kg):		5.75
Non-carcinogen Soil Action Level (mg/kg):		363.57

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		PCE
MW		170
Sol	mg/l	150
Kh	atm m <sup>3</sup> /mole	0.0230
Kh	dimensionless	0.9257
Di-air	cm <sup>2</sup> /sec	0.072
Koc	ml/g	660
CSFo	1/(mg/kg-d)	5.20E-02
CSFi	1/(mg/kg-d)	2.00E-02
RfDo	mg/kg-d	1.00E-02
RfDi	mg/kg-d	1.00E-02

SITE NAME: EXAMPLE #1

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## EXAMPLE 2



EXAMPLE 2. Coastal area over basal, unconfined, non-drinking water groundwater system in silty sediments. Low rainfall (50cm/year). Base of impacted soil  $\leq 5\text{m}$  above top of groundwater. Impacted soil area 30m long by 30m wide and 1m thick. Groundwater gradient assumed to be 0.001.

<sup>1</sup> Contaminant	<sup>2</sup> SESOIL SAL (mg/kg)	<sup>3</sup> Site DAF	<sup>4</sup> Groundwater Protection SAL (mg/kg)	<sup>5</sup> Direct-Exposure SAL (mg/kg)	<sup>6</sup> SAL chosen for site (mg/kg)
Benzene	1.7	2.1	3.6	9.4	3.6
Toluene	34	2.1	71	7576	71
PCE	8.4	2.1	18	6.9	6.9

1. The contaminants noted exceeded Tier 1 soil action levels (SALs) at the example site.
2. Default Tier 1 SESOIL SALs for leachate concerns used rather than re-running the computer application to generate site-specific Tier 2 SALs (refer to Appendix F, Table 1b).
3. Site dilution attenuation factor (DAF) as calculated using DAF spreadsheet (see attached spreadsheet).
4. Site SALs for groundwater-protection concerns calculated by multiplying the SESOIL SAL times the leachate dilution attenuation factor.
5. Contaminant direct-exposure SALs as calculated using DETIER2 spreadsheet (see attached spreadsheet).
6. SAL chosen for site reflects the contaminant pathway of most concern.

## TIER II: SITE-SPECIFIC LEACHATE DILUTION ATTENUATION FACTOR (DAF)

DAF Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

**Calculates dilution attenuation factor for dilution of leachate in groundwater.**

**Applies to basal, unconfined groundwater (aquifer) systems only (refer to Mink and Lau, 1990).**

**For high-level aquifers, input a groundwater gradient of 0.001 unless available data suggest otherwise.**

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. \*Input site data. Use default values where site-specific data are not available.  
3. Spreadsheet generates leachate Dilution Attenuation Factor for site.  
4. Complete information at bottom of this page.

\*Site-specific input data must be supported in text of site investigation report(s).

SITE VARIABLES		DEFAULT	INPUT	Default hydraulic conductivities (m/d)	
<sup>1</sup> Hydraulic Conductivity (m/d):	K	see table	2.0	basalt (all types):	10
Aquifer Thickness (m):	d <sub>a</sub>	10	10	sandy/coralline sediments:	10
Effective Porosity (fraction):	n <sub>eff</sub>	0.30	0.30	saprolite/silty sediments:	2.0
<sup>2</sup> Average site groundwater elevation (m)	E <sub>gw</sub>	site-specific	n/a	clayey sediments or soils:	0.1
<sup>3</sup> Distance to ocean (m)	D	site-specific	n/a		
<sup>4</sup> Source Length (m):	L	site-specific	30		
<sup>5</sup> Precipitation (cm/yr):	p	200	50		
<sup>6</sup> Fraction groundwater recharge:	gw <sub>r</sub>	0.36	0.36		

CALCULATIONS:		
<sup>8</sup> Infiltration Rate (m/y)	I	0.18
<sup>9</sup> Regional Hydraulic Gradient (m/m):	h	0.001
<sup>10</sup> Groundwater Velocity (m/y)	V <sub>s</sub>	2.43
<sup>11</sup> Mixing Zone Depth (m)	d <sub>M</sub>	8.4
<sup>12</sup> Dilution Attenuation Factor:	DAF	2.1

SITE NAME: EXAMPLE #2

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:	
Benzene	
Carcinogen Soil Action Level (mg/kg):	9.40
Non-carcinogen Soil Action Level (mg/kg):	N/A

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	1.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Benzene
MW		78
Sol	mg/l	1800
Kh	atm m <sup>3</sup> /mole	0.0055
Kh	dimensionless	0.2214
Di-air	cm <sup>2</sup> /sec	0.088
Koc	ml/g	65
CSFo	1/(mg/kg-d)	2.90E-02
CSFi	1/(mg/kg-d)	2.90E-02
RfDo	mg/kg-d	
RfDi	mg/kg-d	

SITE NAME:

SITE ADDRESS:

DOH ID NO. \_\_\_\_\_

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

CONTAMINANT: Toluene		
Carcinogen Soil Action Level (mg/kg):		N/A
Non-carcinogen Soil Action Level (mg/kg):		7575.92
Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	1.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

Chemical Data (see below)		Toluene
MW		92
Sol	mg/l	520
Kh	atm m <sup>3</sup> /mole	0.0066
Kh	dimensionless	0.2656
Di-air	cm <sup>2</sup> /sec	0.078
Koc	ml/g	260
CSFo	1/(mg/kg-d)	
CSFi	1/(mg/kg-d)	
RfDo	mg/kg-d	2.00E-01
RfDi	mg/kg-d	1.10E-01

SITE NAME: EXAMPLE #2

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:		PCE
Carcinogen Soil Action Level (mg/kg):		6.87
Non-carcinogen Soil Action Level (mg/kg):		466.77

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	1.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		PCE
MW		170
Sol	mg/l	150
Kh	atm m <sup>3</sup> /mole	0.0230
Kh	dimensionless	0.9257
Di-air	cm <sup>2</sup> /sec	0.072
Koc	ml/g	660
CSFo	1/(mg/kg-d)	5.20E-02
CSFi	1/(mg/kg-d)	2.00E-02
RfDo	mg/kg-d	1.00E-02
RfDi	mg/kg-d	1.00E-02

SITE NAME: EXAMPLE #2

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

### EXAMPLE 3

EXAMPLE 3. Inland area over basal, unconfined, drinking water groundwater system in basalt. Low rainfall (50cm/year). Base of impacted soil  $\geq 10\text{m}$  above top of groundwater. Impacted soil 30m long by 30m wide and 2m thick. Groundwater gradient assumed to be 0.001.

<sup>1</sup> Contaminant	<sup>2</sup> SESOIL SAL (mg/kg)	<sup>3</sup> Site DAF	<sup>4</sup> Groundwater Protection SAL (mg/kg)	<sup>5</sup> Direct-Exposure SAL (mg/kg)	<sup>6</sup> SAL chosen for site (mg/kg)
Benzene	0.027	4.1	0.11	6.8	0.11
Toluene	124	4.1	<sup>4</sup> 170sat	5340	170
PCE	2.3	4.1	9.4	5.8	5.8

1. The contaminants noted exceeded Tier 1 soil action levels (SALs) at the example site.
2. Default Tier 1 SESOIL SALs for leachate concerns used rather than re-running the computer application to generate site-specific Tier 2 SALs (refer to Appendix F, Table 1a).
3. Site dilution attenuation factor (DAF) as calculated using DAF spreadsheet (see attached spreadsheet).
4. Site SALs for groundwater-protection concerns calculated by multiplying the SESOIL SAL times the leachate dilution attenuation factor. Maximum groundwater-protection SAL is the contaminants theoretical saturation limit ("sat", refer to Appendix F, Table 2).
5. Contaminant direct-exposure SALs as calculated using DETIER2 spreadsheet (see attached spreadsheet).
6. SAL chosen for site reflects the contaminant pathway of most concern.

## TIER II: SITE-SPECIFIC LEACHATE DILUTION ATTENUATION FACTOR (DAF)

DAF Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

**Calculates dilution attenuation factor for dilution of leachate in groundwater.**

**Applies to basal, unconfined groundwater (aquifer) systems only (refer to Mink and Lau, 1990).**

**For high-level aquifers, input a groundwater gradient of 0.001 unless available data suggest otherwise.**

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. \*Input site data. Use default values where site-specific data are not available.  
3. Spreadsheet generates leachate Dilution Attenuation Factor for site.  
4. Complete information at bottom of this page.

\*Site-specific input data must be supported in text of site investigation report(s).

SITE VARIABLES		DEFAULT	INPUT	Default hydraulic conductivities (m/d)	
<sup>1</sup> Hydraulic Conductivity (m/d):	K	see table	10.0	basalt (all types):	10
Aquifer Thickness (m):	d <sub>a</sub>	10	10	sandy/coralline sediments:	10
Effective Porosity (fraction):	n <sub>eff</sub>	0.30	0.30	saprolite/silty sediments:	2.0
<sup>2</sup> Average site groundwater elevation (m)	E <sub>gw</sub>	site-specific	n/a	clayey sediments or soils:	0.1
<sup>3</sup> Distance to ocean (m)	D	site-specific	n/a		
<sup>4</sup> Source Length (m):	L	site-specific	30		
<sup>5</sup> Precipitation (cm/yr):	p	200	50		
<sup>6</sup> Fraction groundwater recharge:	gw <sub>r</sub>	0.36	0.36		

CALCULATIONS:		
<sup>8</sup> Infiltration Rate (m/y)	I	0.18
<sup>9</sup> Regional Hydraulic Gradient (m/m):	h	0.001
<sup>10</sup> Groundwater Velocity (m/y)	V <sub>s</sub>	12.17
<sup>11</sup> Mixing Zone Depth (m)	d <sub>M</sub>	4.6
<sup>12</sup> Dilution Attenuation Factor:	DAF	4.1

SITE NAME: EXAMPLE #3

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):



## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:	
Benzene	
Carcinogen Soil Action Level (mg/kg):	6.78
Non-carcinogen Soil Action Level (mg/kg):	N/A

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Benzene
MW		78
Sol	mg/l	1800
Kh	atm m <sup>3</sup> /mole	0.0055
Kh	dimensionless	0.2214
Di-air	cm <sup>2</sup> /sec	0.088
Koc	ml/g	65
CSFo	1/(mg/kg-d)	2.90E-02
CSFi	1/(mg/kg-d)	2.90E-02
RfDo	mg/kg-d	
RfDi	mg/kg-d	

SITE NAME: EXAMPLE #3

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:	
Toluene	
Carcinogen Soil Action Level (mg/kg):	N/A
Non-carcinogen Soil Action Level (mg/kg):	5339.54

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Toluene
MW		92
Sol	mg/l	520
Kh	atm m <sup>3</sup> /mole	0.0066
Kh	dimensionless	0.2656
Di-air	cm <sup>2</sup> /sec	0.078
Koc	ml/g	260
CSFo	1/(mg/kg-d)	
CSFi	1/(mg/kg-d)	
RfDo	mg/kg-d	2.00E-01
RfDi	mg/kg-d	1.10E-01

SITE NAME: EXAMPLE #3

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:		PCE
Carcinogen Soil Action Level (mg/kg):		5.75
Non-carcinogen Soil Action Level (mg/kg):		363.57

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		PCE
MW		170
Sol	mg/l	150
Kh	atm m <sup>3</sup> /mole	0.0230
Kh	dimensionless	0.9257
Di-air	cm <sup>2</sup> /sec	0.072
Koc	ml/g	660
CSFo	1/(mg/kg-d)	5.20E-02
CSFi	1/(mg/kg-d)	2.00E-02
RfDo	mg/kg-d	1.00E-02
RfDi	mg/kg-d	1.00E-02

SITE NAME: EXAMPLE #3

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

#### EXAMPLE 4

EXAMPLE 4. Inland area over high-level, unconfined drinking water groundwater system in basalt. Moderate rainfall (150cm/year). Base of impacted soil  $\leq 5\text{m}$  above top of groundwater. Impacted soil 30m long by 30m wide and 2m thick. Groundwater gradient assumed to be 0.001.

<sup>1</sup> Contaminant	<sup>2</sup> SESOIL SAL (mg/kg)	<sup>3</sup> Site DAF	<sup>4</sup> Groundwater Protection SAL (mg/kg)	<sup>5</sup> Direct-Exposure SAL (mg/kg)	<sup>6</sup> SAL chosen for site (mg/kg)
Benzene	0.005	2.5	<sup>7</sup> 0.050	6.8	0.050
Toluene	16	2.5	40	5340	40
PCE	0.29	2.5	0.73	5.8	0.73

1. The contaminants noted exceeded Tier 1 soil action levels (SALs) at the example site.
2. Default Tier 1 SESOIL SALs for leachate concerns used rather than re-running the computer application to generate site-specific Tier 2 SALs (refer to Appendix F, Table 1a).
3. Site dilution attenuation factor (DAF) as calculated using DAF spreadsheet (see attached spreadsheet).
4. Site SALs for groundwater-protection concerns calculated by multiplying the SESOIL SAL times the leachate dilution attenuation factor.
5. Contaminant direct-exposure SALs as calculated using DETIER2 spreadsheet (see attached spreadsheet).
6. SAL chosen for site reflects the contaminant pathway of most concern.
7. DOH has set a lower limit for benzene groundwater-protection SAL of 0.05mg/kg rather than using the SESOIL-generated SAL (see Appendix F, Table 1 and Table 1-1 of main text).

## TIER II: SITE-SPECIFIC LEACHATE DILUTION ATTENUATION FACTOR (DAF)

DAF Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

**Calculates dilution attenuation factor for dilution of leachate in groundwater.**

**Applies to basal, unconfined groundwater (aquifer) systems only (refer to Mink and Lau, 1990).**

**For high-level aquifers, input a groundwater gradient of 0.001 unless available data suggest otherwise.**

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. \*Input site data. Use default values where site-specific data are not available.  
3. Spreadsheet generates leachate Dilution Attenuation Factor for site.  
4. Complete information at bottom of this page.

\*Site-specific input data must be supported in text of site investigation report(s).

SITE VARIABLES		DEFAULT	INPUT	Default hydraulic conductivities (m/d)	
<sup>1</sup> Hydraulic Conductivity (m/d):	K	see table	10.0	basalt (all types):	10
Aquifer Thickness (m):	d <sub>a</sub>	10	10	sandy/coralline sediments:	10
Effective Porosity (fraction):	n <sub>eff</sub>	0.30	0.30	saprolite/silty sediments:	2.0
<sup>2</sup> Average site groundwater elevation (m)	E <sub>gw</sub>	site-specific	n/a	clayey sediments or soils:	0.1
<sup>3</sup> Distance to ocean (m)	D	site-specific	n/a		
<sup>4</sup> Source Length (m):	L	site-specific	30		
<sup>5</sup> Precipitation (cm/yr):	p	200	150		
<sup>6</sup> Fraction groundwater recharge:	gw <sub>r</sub>	0.36	0.36		

CALCULATIONS:		
<sup>8</sup> Infiltration Rate (m/y)	I	0.54
<sup>9</sup> Regional Hydraulic Gradient (m/m):	h	0.001
<sup>10</sup> Groundwater Velocity (m/y)	V <sub>s</sub>	12.17
<sup>11</sup> Mixing Zone Depth (m)	d <sub>M</sub>	6.8
<sup>12</sup> Dilution Attenuation Factor:	DAF	2.5

SITE NAME: EXAMPLE #4

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:	
Benzene	
Carcinogen Soil Action Level (mg/kg):	6.78
Non-carcinogen Soil Action Level (mg/kg):	N/A

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Benzene
MW		78
Sol	mg/l	1800
Kh	atm m <sup>3</sup> /mole	0.0055
Kh	dimensionless	0.2214
Di-air	cm <sup>2</sup> /sec	0.088
Koc	ml/g	65
CSFo	1/(mg/kg-d)	2.90E-02
CSFi	1/(mg/kg-d)	2.90E-02
RfDo	mg/kg-d	
RfDi	mg/kg-d	

SITE NAME: EXAMPLE #4

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:	
Toluene	
Carcinogen Soil Action Level (mg/kg):	N/A
Non-carcinogen Soil Action Level (mg/kg):	5339.54

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		Toluene
MW		92
Sol	mg/l	520
Kh	atm m <sup>3</sup> /mole	0.0066
Kh	dimensionless	0.2656
Di-air	cm <sup>2</sup> /sec	0.078
Koc	ml/g	260
CSFo	1/(mg/kg-d)	
CSFi	1/(mg/kg-d)	
RfDo	mg/kg-d	2.00E-01
RfDi	mg/kg-d	1.10E-01

SITE NAME: EXAMPLE #4

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):



## TIER II DIRECT-EXPOSURE RISK ASSESSMENT MODEL

DETIER2 Version: November 1995  
State of Hawai'i  
Department of Health  
Environmental Management Division

Assumes residential exposure by ingestion, inhalation, & dermal contact.

Assumes impacted soil is or could potentially be exposed at the surface.

Does not address potential groundwater impact or indoor air concerns.

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. \*Input site data. Use default values where site-specific data are not available.  
4. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
5. Spreadsheet generates direct-exposure SALs for site (see accompanying document).  
6. Complete information at bottom of this page. Submit printout of spreadsheet with appropriate documents.

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

### VOLATILE CONTAMINANT

MASS-BALANCE

MODEL USED

(refer to note #7)

CONTAMINANT:		PCE
Carcinogen Soil Action Level (mg/kg):		5.75
Non-carcinogen Soil Action Level (mg/kg):		363.57

Site Data	DEFAULT	INPUT
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	900
Thickness impacted soil (m)	N/A	2.00
Soil density (g/cm <sup>3</sup> )	1.50	1.50
Particle density (g/cm <sup>3</sup> )	2.65	2.65
Soil moisture content (ml/g)	0.10	0.10
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002
Fraction surface covered/vegetated	0.50	0.50
Windspeed (m/s)	2.5	2.5

Chemical Data (see below)		PCE
MW		170
Sol	mg/l	150
Kh	atm m <sup>3</sup> /mole	0.0230
Kh	dimensionless	0.9257
Di-air	cm <sup>2</sup> /sec	0.072
Koc	ml/g	660
CSFo	1/(mg/kg-d)	5.20E-02
CSFi	1/(mg/kg-d)	2.00E-02
RfDo	mg/kg-d	1.00E-02
RfDi	mg/kg-d	1.00E-02

SITE NAME: EXAMPLE #4

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

## **APPENDIX J**

### **EXAMPLE TIER 3 DIRECT-EXPOSURE SPREADSHEET RESULTS**

**TIER III DIRECT-EXPOSURE RISK ASSESSMENT MODEL**

DETIER3 Version: November 1995

State of Hawai'i

Department of Health

Environmental Management Division

**Assumes impacted soil is or could potentially be exposed at the surface.****Does not address potential groundwater impact or indoor air concerns.**

- STEPS.** 1. Check with DOH to ensure that this is an up-to-date version of the spreadsheet.  
2. Check with DOH to ensure that the default toxicity data provided is up-to-date.  
3. Denote exposure pathways to be evaluated.  
4. \*Input site data. Use default values where site-specific data are not available.  
5. \*Input alternative human receptor exposure data where applicable.  
6. Input default physio-chemical data. (Copy & paste from end of spreadsheet.)  
7. Spreadsheet generates Risk or HQ at site (see accompanying document).  
8. Complete information at bottom of this page.

**\*PATHWAYS EVALUATED:**

(Mark yes "Y" or no "N")

Inhalation: Y

Ingestion: Y

Dermal absorption: Y

[\*Site-specific input data must be supported in text of site investigation report(s). For soil with mixtures of contaminants, assume that no more than 10% of the total soil organic carbon (foc) is available for adsorption of any one contaminant. Note that input foc does not affect SAL results when mass-balance model or particulate-emission models are used and input soil thickness does not affect SAL results when the PRG or particulate-emission models are used. See text.]

**VOLATILE CONTAMINANT**

CONTAMINANT:	Benzene	Residential	*Occupational
Risk (number per million):		1.00	0.19
Hazard Quotient:		N/A	N/A

MASS-BALANCE

MODEL USED

(refer to note #7)

Site Data	DEFAULT	INPUT	Chemical Data (see below)	Benzene
Soil concentration (mg/kg)	N/A	5.31	MW	78
<sup>2</sup> Area impacted soil (m <sup>2</sup> )	N/A	2025	Sol mg/l	1800
Thickness impacted soil (m)	N/A	2.00	Kh atm m <sup>3</sup> /mole	0.0055
Soil density (g/cm <sup>3</sup> )	1.50	1.50	Kh dimensionless	0.2214
Particle dns. (g/cm)	2.65	2.65	Di-air cm <sup>2</sup> /sec	0.088
Soil moisture content (ml/g)	0.10	0.10	Koc ml/g	65
<sup>3</sup> Fraction organic carbon in soil	0.002	0.002	CSFo 1/(mg/kg-d)	2.90E-02
Fraction surface covered/vegetated	0.50	0.50	CSFi 1/(mg/kg-d)	2.90E-02
Windspeed (m/s)	2.5	2.5	RfDo mg/kg-d	
			RfDi mg/kg-d	

SITE NAME:

DOH ID NO. \_\_\_\_\_

SITE ADDRESS:

SPREADSHEET PREPARED BY: \_\_\_\_\_

DATE: \_\_\_\_\_

SIGNATURE: \_\_\_\_\_

SUPPORTING SITE INVESTIGATION REPORT(S) (Note report title, date, and preparer's name and address):

Human Receptor Data (fixed)			INPUT
25% surface area - adults	SAa	cm <sup>2</sup>	5000
25% surface area - children	SAc	cm <sup>2</sup>	2000
Adherence factor	AF	mg/cm <sup>2</sup>	0.2
Skin absorption factor	ABS	unitless	0.10
Inhalation Rate - adults	IRAa	m <sup>3</sup> /d	20
Inhalation Rate - children	IRAc	m <sup>3</sup> /d	10
Soil ingestion rate - adults	IRSA	mg/d	100
Soil ingestion rate - children	IRSc	mg/d	200
Soil ingestion rate - occupational	IRSo	mg/d	50
Exposure time - residents	ETr	h/d	24
Exposure time - occupational	ETo	h/d	12
Exposure frequency - residents	EFr	d/y	350
Exposure frequency - occupational	EFo	d/y	250
Exposure duration - residents total	EDr	yrs	30
Exposure duration - children	EDc	yrs	6
Exposure duration - occupational	EDo	yrs	25
Body weight - adult	BWa	kg	70
Body weight - child	BWc	kg	15
Averaging time (years)	AT	yrs	70
Days/year conversion		d/yr	365

<b>Other variables (fixed)</b>			
Surface diffusion height	DH	m	2
<b><sup>4</sup>Calculations</b>			
<b>Various:</b>			
Side perpendicular to wind (assumed = area <sup>0.5</sup> )	LS	m	45
Soil porosity			0.43
Soil air-filled porosity	Pa		0.28
Soil-water partition coeff.	Kd	cm <sup>3</sup> /g	1.30E-01
<sup>5</sup> Air exchange rate - outdoor	ER	m <sup>3</sup> /sec	2.25E+02
Ingestion exposure factor	IFS	mg-yr/kg-d	114
Skin contact exposure factor	SFS	mg-yr/kg-d	503
Inhalation exposure factor	InhF	mg <sup>3</sup> -yr/kg-d	11
<b>OUTDOOR EXPOSURE (INHALATION, INGESTION, DERMAL ABSORPTION)</b>			
<b>Impacted-Soil Emissions:</b>			
Effective diffusivity - soil to air	De <sub>sa</sub>	cm <sup>2</sup> /sec	7.06E-03
<sup>6</sup> Volatilization factor - modified PRG	VF <sub>prgr</sub>	kg/m <sup>3</sup>	3.07E+03
<sup>7</sup> Volatilization factor - mass balanced	VF <sub>mbr</sub>	kg/m <sup>3</sup>	3.50E+04
<sup>8</sup> Volatilization factor - used for model	VF <sub>mod</sub>	kg/m <sup>3</sup>	3.50E+04
<sup>9</sup> Surface emission rate	Ei	g/sec	3.41E-05
<sup>10</sup> Particulate emission factor	PEF	kg/m <sup>3</sup>	1.61E+06
<sup>11</sup> Particulate emission rate	PEi	kg/m <sup>2</sup> -sec	7.42E-07
<sup>12</sup> Air concentration - volatile	Ca <sub>v</sub>	mg/m <sup>3</sup>	1.52E-04
<sup>12</sup> Air concentration - particulate	Ca <sub>p</sub>	mg/m <sup>3</sup>	3.30E-06
<sup>13</sup> Risk - residential	R <sub>r</sub>	# per million	1.00E+00
<sup>14</sup> Risk - industrial	R <sub>i</sub>	# per million	1.94E-01
<sup>15</sup> HQ - residential	HQ <sub>r</sub>		0.00E+00
<sup>16</sup> HQ - industrial	HQ <sub>i</sub>		0.00E+00
<b>Other:</b>			
<sup>17</sup> Mass of impacted soil		g	6.08E+06

#### NOTES:

1. Use default chemical and toxicity data provided in EPA Region IX PRGs (from IRIS data base), First Half, 1995, or as otherwise directed or approved by DOH.
2. Total areal extent of contamination above Tier 1 soil action levels. Used to calculate mass of contaminant at site. Does not affect resulting Tier 2 SAL. (Tier 2 SAL controlled by length of site parallel to wind direction. See note 6.)
3. For soils contaminated with a mixture of contaminants (e.g., petroleum), assume a default foc of 0.002 or a maximum of 10% of the measured total soil foc. For soils contaminated with a pure product, assume a default foc of 0.02 or the measured total soil foc.
4. Calculations based on modified equations presented in EPA Region IX PRGs (see text).
5. ER (or "dispersion factor") for outdoor air calculated using  $ER = LS \times V \times DH$ . (Refer to California Preliminary Endangerment Assessment Guidance Manual, pg. B-3. ER term Incorporated into August 1, 1994, EPA Region IX PRGs "Volatilization Factor" equation 3-9. Also incorporated into ASTM RBCA guidance, Table X2.1. Air exchange rate/area term in 1994 PRGs replaced with default "Q/C" value in 1995 PRG model. See also note 7.)
6. Volatilization factor calculated using modification of equation 4-9 in EPA Region IX PRGs, First Half, 1995. PRG equation is equivalent to "air dispersion term/(emission rate/soil concentration)" as can be generated using equations presented in Fig. 2-7 (emission rate) and on pg B-3 (includes air exchange rate) in California Preliminary Endangerment Assessment Guidance Manual. (See also notes 5 & 6.)
7. Mass-balanced volatilization factor. Takes into account the thickness of soil impacted with volatile contaminants. (Not applicable for semi-volatile and non-volatile contaminants.) Calculated by dividing the total contaminant mass by the total exposure duration. Reflects the maximum, average emission rate required for the source to be completely exhausted at the end of the input exposure duration. (i.e., Worst-case scenario. All of the contaminant is emitted from the soil during the exposure period.)
8. Volatilization factor used for site model. Greater of the PRG and mass-balanced VFs (see text).
9. Volatile emission rate ( $E_i$ ) for given site scenario. Calculated by dividing the soil concentration by the corresponding volatilization factor. Used in risk equations to calculate concentration of contaminant in air.
10. Particulate emission factor calculated using equation 4-11 from EPA Region IX PRGs, First Half, 1995, but substituting air exchange rate/area ( $ER/A$ ) for the term  $Q/C$ . (Refer to notes 5 & 6.) ASTM default particulate emission rate is  $6.9E-13 \text{ kg/m}^2\text{-s}$ .
11. Non-volatile emission rate ( $E_i$ ) for given site scenario. Calculated by dividing the soil concentration by the corresponding corresponding PEF. Used to calculate concentration of contaminant in air.
12. Concentration of contaminant in air. Calculated by dividing soil contaminant concentration by corresponding VF or PEF.
13. Based on equation 4-1 in EPA Region IX PRGs, First Half, 1995.
14. Based on equation 4-3 in EPA Region IX PRGs, First Half, 1995.
15. Based on equation 4-2 in EPA Region IX PRGs, First Half, 1995.
16. Based on equation 4-4 in EPA Region IX PRGs, First Half, 1995.
17. Mass of impacted soil = area ( $\text{cm}^2$ ) x thickness (cm) x density ( $\text{g/cm}^3$ )

#### REFERENCES:

- ASTM. 1994. *Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. Designation ES 38-94. Philadelphia, Pennsylvania.
- California EPA. 1994. *Preliminary Endangerment Assessment Guidance Manual*. Department of Toxic Substances Control, Sacramento, California.
- HIDOH. 1995. *Risk-Based Corrective Action And Decision Making At Sites With Contaminated Soil And Groundwater*: Hawai'i Department of Health, Environmental Management Division.
- U.S. EPA. 1994. *Region IX Preliminary Remediation Goals (PRGs) Second Half, 1994*. Technical Support Section, San Francisco, California.
- U.S. EPA. 1995. *Region IX Preliminary Remediation Goals (PRGs) First Half, 1995*. Technical Support Section, San Francisco, California.

**APPENDIX K**

**SUPPORTING DATA FOR TIER 1 ACTION LEVELS  
GENERATED USING SESOIL**

# **SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALS)** **Drinking water source threatened; annual rainfall = 200cm** **Tier 1 SALS directly generated using SESOIL (see text)**

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated Input soil concentration (ug/g)	T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
Benzene	.005	5	2nd yr, 3rd mo	7,375	36.9	.018	1st yr, 4th mo	1,487	.005	8/18/95	RDB
Benzene	.005	10	3rd yr, 2nd mo	6,707	33.5	.09	1st yr, 4th mo	7,997	.027	8/18/95	RDB
Benzene	.005	20	4th yr, 12th mo	3,739	18.7	1.22	1st yr, 4th mo	71,098	.24	8/18/95	RDB
Benzene	.005	30	6th yr, 9th mo	4,289	21.5	3.88	1st yr, 4th mo	337,730	1.13	8/18/95	RDB
Benzene	.005	40	8th yr, 7th mo	7,260	36.3	14.7	1st yr, 4th mo	1,277,100	4.26	8/18/95	RDB
Benzene	.005	50	10th yr, 5th mo	6,894	34.5	47	1st yr, 4th mo	4,081,400	13.6	8/18/95	RDB
Benzene	.005	75	14th yr, 8th mo	6,230	31.1	400	1st yr, 4th mo	44,209,000	147	8/18/95	RDB
Benzene	.005	80	15th yr, 6th mo	7,785	38.9	> saturation at T-1	1st yr, 4th mo	63,430,000	210 (saturation)	8/18/95	RDB
Toluene	1.0	5	3rd yr, 5th mo	6,275	6,275	245	1st yr, 11th mo	4,844,400	16.1	8/18/95	RDB
Toluene	1.0	10	4th yr, 7th mo	7,255	7,255	645	1st yr, 12th mo	37,135,000	124	8/18/95	RDB
Toluene	1.0	20	7th yr, 1st mo	5,537	5,537	> saturation at T-1	1st yr, 12th mo	50,389,000	170 (saturation)	8/18/95	RDB
Ethylbenzene	0.14	5	3rd yr, 4th mo	10,567	1,479	2.1	1st yr, 9th mo	142,194	0.50	8/23/95	RDB
Ethylbenzene	0.14	10	4th yr, 7th mo	7,255	1,016	9.3	1st yr, 11th mo	442,930	1.5	8/23/95	RDB
Ethylbenzene	0.14	20	7th yr, 4th mo	10,622	1,487	83.2	1st yr, 11th mo	3,959,900	13.2	8/23/95	RDB
Ethylbenzene	0.14	30	9th yr, 11th mo	4,299	602	310	1st yr, 12th mo	13,647,500	46	8/23/95	RDB
Ethylbenzene	0.14	40	12th yr, 6th mo	8,003	1,120	575	1st yr, 12th mo	49,350,000	165	8/23/95	RDB
Ethylbenzene	0.14	50	15th yr, 2nd mo	6,355	890	> saturation at T-1	1st yr, 12th mo	59,444,000	200 (saturation)	8/23/95	RDB
Xylene	10	5	3rd yr, 2nd mo	6,584	65,840	77	1st yr, 9th mo	6,864,000	23	8/23/95	RDB
Xylene	10	10	4th yr, 3rd mo	7,255	72,550	> saturation at T-1	1st yr, 11th mo	17,586,800	59 (saturation)	8/23/95	RDB
Benzo(a)pyrene	0.0002	5	>20 years				<1m after 20 yrs	1,020,000	3.4 (saturation)	9/4/95	RDB
Acenaphthene	0.32	5	>20 years				12th yr, 10th mo	5,400,000	18 (saturation)	9/4/95	RDB
Fluoranthene	0.013	5	>20 years				<1m after 20yrs	3,300,000	11 (saturation)	9/4/95	RDB
Naphthalene	0.24	5	8th yr, 4th mo	10,657	2,558	> saturation at T-1	4th yr, 7th mo	12,300,000	41 (saturation)	9/4/95	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)



**SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALS)**  
**Drinking water source threatened; annual rainfall = 200cm**  
**Tier 1 SALS directly generated using SESOIL (see text)**

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated input soil concentration (ug/g)	T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
PCE	0.005	5	7th yr, 4th mo	10,567	52.8	10.9	3rd yr, 4th mo	85,711	0.29	9/4/95	RDB
PCE	0.005	10	10th yr, 11th mo	4,406	22.0	124	3rd yr, 6th mo	693,230	2.3	9/4/95	RDB
PCE	0.005	20	18th yr, 2nd mo	6,473	32.4	500	3rd yr, 8th mo	9,365,900	31	9/4/95	RDB
PCE	0.005	30	>20 years			> saturation at T-1	3rd yr, 9th mo	1,864,280	130 (saturation)	9/4/95	RDB
1,1 DCE	0.046	5	18th yr, 3rd mo	7,375	339	> saturation at T-1	4th yr, 4th mo	145,497,000	490 (saturation)	9/3/95	RDB
Vinyl Chloride	0.002	5	>20 years			> saturation at T-1	16th yr, 1st mo	1,768,500,000	5,900 (saturation)	9/4/95	RDB
TCE	0.005	5	2nd yr, 11th mo	4,308	21.5	0.04	1st yr, 6th mo	3,425	0.01	9/14/95	RDB
TCE	0.005	10	4th yr, 4th mo	10,402	52.0	0.19	1st yr, 7th mo	12,322	0.04	9/14/95	RDB
TCE	0.005	20	7th yr, 2nd mo	6,473	32.4	1.22	1st yr, 7th mo	78,933	0.26	9/14/95	RDB
TCE	0.005	30	9th yr, 10th mo	4,005	20.0	4.1	1st yr, 7th mo	263,570	0.89	9/14/95	RDB
TCE	0.005	40	12th yr, 8th mo	5,761	28.8	10.3	1st yr, 7th mo	657,780	2.2	9/14/95	RDB
TCE	0.005	50	15th yr, 5th mo	6,894	34.5	21.2	1st yr, 7th mo	1,346,570	4.5	9/14/95	RDB
TCE	0.005	70	20th yr, 11th mo	4,432	22.2	60.0	1st yr, 8th mo	2,959,800	9.9	9/14/95	RDB
1,1,1 TCA	0.20	5	2nd yr, 5th mo	6,275	1,255	0.18	1st yr, 6th mo	29,523	0.10	9/14/95	RDB
1,1,1 TCA	0.20	10	3rd yr, 1st mo	5,543	1,109	0.31	1st yr, 6th mo	53,278	0.18	9/14/95	RDB
1,1,1 TCA	0.20	20	4th yr, 4th mo	10,622	2,124	0.91	1st yr, 6th mo	159,250	0.53	9/14/95	RDB
1,1,1 TCA	0.20	30	5th yr, 6th mo	7,580	1,516	1.78	1st yr, 6th mo	313,360	1.0	9/14/95	RDB
1,1,1 TCA	0.20	40	6th yr, 8th mo	5,761	1,152	3.02	1st yr, 7th mo	464,800	1.5	9/14/95	RDB
1,1,1 TCA	0.20	50	7th yr, 10th mo	3,972	784	4.67	1st yr, 7th mo	720,430	2.4	9/14/95	RDB
1,1,1 TCA	0.20	75	10th yr, 7th mo	7,731	1,546	12.8	1st yr, 7th mo	1,979,100	6.6	9/14/95	RDB
1,1,1 TCA	0.20	100	13th yr, 2nd mo	6,391	1,278	25.5	1st yr, 7th mo	3,944,900	13	9/14/95	RDB
Acetone	0.61	5	1st yr, 3rd mo	7,375	4,499	118	1st yr, 1st mo	1,729,120	5.76	2/24/96	RDB
Chlorobenzene	0.10	5	2nd yr, 6th mo	7,871	787	0.15	1st yr, 6th mo	22,766	0.076	2/24/96	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALS)

Drinking water source threatened; annual rainfall = 200cm

Tier 1 SALS directly generated using SESOIL (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated input soil concentration (ug/g)	T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
Chloroform	0.00016	5	2nd yr, 1st mo	5,568	0.89	0.0042	1st yr, 3rd mo	202.6	0.007	2/24/96	RDB
4,4 DDD	0.003	5	> 20 years			> saturation at T-1	<1m after 20yrs	37,260,687	124 (saturation)	2/24/96	RDB
4,4 DDE	0.002	5	> 20 years			> saturation at T-1	<1m after 20yrs	158,400,528	528 (saturation)	2/24/96	RDB
4,4 DDT	0.002	5	> 20 years			> saturation at T-1	<1m after 20yrs	244,718	0.82 (saturation)	2/24/96	RDB
Di-n-octyl phthalate	0.73	5	> 20 years			> saturation at T-1	<1m after 20yrs	9,152,921	31 (saturation)	2/24/96	RDB
Ethylene glycol	73,000	5	1st yr, 3rd mo	7,375	5.4E+08	> saturation at T-1	1st yr, 1st mo	5,444,000,000	18,147 (saturation)	2/24/96	RDB
Methylene chloride	0.0043	5	1st yr, 7th mo	7,048	30.3	0.0126	1st yr, 2nd mo	802.6	0.0027	2/24/96	RDB
2,3,7,8 TCDD	4.5E-10	5	> 20 years			> saturation at T-1	<1m after 20yrs	21,000,000	70 (saturation)	6/5/96	RDB
Chlordane	0.002	5	> 20 yrs				<1m after 20yrs	6,559,161	22 (saturation)	6/12/95	RDB
Carbon tetrachloride	0.005	5	4th yr, 6th mo	7,871	39	2.66	1st yr, 10th mo	45,920	0.15	6/12/95	RDB
Carbon tetrachloride								69,635,000 (sat)	232 (saturation)	6/12/96	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source not threatened; annual rainfall = 200cm

Tier 1 SALs Indirectly generated using SALs generated for drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source threatened (mg/kg)	Conversion factor	Tier 1 SAL for drinking-water source not threatened (mg/kg)	Date modeled	Modeled by
Benzene	1.7	5	0.005	340	1.7	8/18/95	RDB
Benzene	1.7	10	0.027	340	9.2	8/18/95	RDB
Benzene	1.7	20	0.24	340	81.6	8/18/95	RDB
Benzene	1.7	30	1.13	340	210 (saturation)	8/18/95	RDB
Toluene	2.1	5	18.1	2.1	34	8/18/95	RDB
Toluene	2.1	10	124	2.1	170 (saturation)	8/18/95	RDB
Ethylbenzene	0.14	5	0.50	1	0.50	8/23/95	RDB
Ethylbenzene	0.14	10	1.5	1	1.5	8/23/95	RDB
Ethylbenzene	0.14	20	13.2	1	13.2	8/23/95	RDB
Ethylbenzene	0.14	30	46	1	46	8/23/95	RDB
Ethylbenzene	0.14	40	165	1	165	8/23/95	RDB
Ethylbenzene	0.14	50	200 (saturation)	-	200 (saturation)	8/23/95	RDB
Xylene	10	5	23	1	23	8/23/95	RDB
Xylene	10	10	59 (saturation)	-	59 (saturation)	8/23/95	RDB
Benzo(a)pyrene	0.0002	5	3.4 (saturation)	-	3.4 (saturation)	9/4/95	RDB
Acenaphthene	0.32	5	18 (saturation)	-	18 (saturation)	9/4/95	RDB
Fluoranthene	0.013	5	11 (saturation)	-	11 (saturation)	9/4/95	RDB
Naphthalene	0.77	5	41 (saturation)	-	41 (saturation)	9/4/95	RDB
PCE	0.145	5	0.29	29	8.4	9/4/95	RDB
PCE	0.145	10	2.30	29	67	9/4/95	RDB
PCE	0.145	20	31.2	29	130 (saturation)	9/4/95	RDB

Conversion Factor calculated as: non-drinking water GAL/drinking water GAL  
Soil action level calculated as: drinking water source threatened SAL x conversion factor

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source not threatened; annual rainfall = 200cm

Tier 1 SALs Indirectly generated using SALs generated for drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source		Conversion factor	Tier 1 SAL for drinking-water source not threatened (mg/kg)		Date modeled	Modeled by
			Threatened (mg/kg)	Not Threatened (mg/kg)		Threatened (mg/kg)	Not Threatened (mg/kg)		
1,1 DCE	3.9	5	490 (saturation)	-	-	490 (saturation)	-	9/3/95	RDB
Vinyl Chloride	0.002	5	5,900 (saturation)	-	-	5,900 (saturation)	-	9/4/95	RDB
TCE	0.70	5	0.011	-	140	1.5	-	9/14/95	RDB
TCE	0.70	10	0.041	-	140	5.7	-	9/14/95	RDB
TCE	0.70	20	0.26	-	140	36	-	9/14/95	RDB
TCE	0.70	30	0.89	-	140	125	-	9/14/95	RDB
TCE	0.70	40	2.19	-	140	210 (saturation)	-	9/14/95	RDB
1,1,1 TCA	6.0	5	0.10	-	30	3.0	-	9/14/95	RDB
1,1,1 TCA	6.0	10	0.18	-	30	5.4	-	9/14/95	RDB
1,1,1 TCA	6.0	20	0.53	-	30	16	-	9/14/95	RDB
1,1,1 TCA	6.0	30	1.04	-	30	31	-	9/14/95	RDB
1,1,1 TCA	6.0	40	1.55	-	30	47	-	9/14/95	RDB
1,1,1 TCA	6.0	50	2.4	-	30	72	-	9/14/95	RDB
1,1,1 TCA	6.0	75	6.6	-	30	170 (saturation)	-	9/14/95	RDB
Acetone	0.61	5	5.76	-	1	5.76	-	2/24/96	RDB
Chlorobenzene	0.10	5	0.076	-	1	0.076	-	2/24/96	RDB
Chloroform	9.6	5	0.007	-	6,000	42	-	2/24/96	RDB
4,4 DDD	0.6	5	124 (saturation)	-	-	124 (saturation)	-	2/24/96	RDB
4,4 DDE	0.014	5	528 (saturation)	-	-	528 (saturation)	-	2/24/96	RDB
4,4 DDT	0.000001	5	0.82 (saturation)	-	-	0.82 (saturation)	-	2/24/96	RDB
Di-n-octyl phthalate	0.73	5	31 (saturation)	-	-	31 (saturation)	-	2/24/96	RDB
Ethylene glycol	73,000	5	18,147 (saturation)	-	-	18,147 (saturation)	-	2/24/96	RDB
Methylene chloride	0.0043	5	0.0027	-	1	0.0027	-	2/24/96	RDB

Conversion Factor calculated as: non-drinking water GAL/drinking water GAL  
Soil action level calculated as: drinking water source threatened SAL x conversion factor

# **SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)**

Drinking water source not threatened; annual rainfall = 200cm

Tier 1 SALs indirectly generated using SALs generated for drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source		Conversion factor	Tier 1 SAL for drinking-water source not threatened (mg/kg)		Date modeled	Modeled by
			Threatened (mg/kg)	Not Threatened (mg/kg)		Threatened (mg/kg)	Not Threatened (mg/kg)		
2,3,7,8 TCDD	0.003	5	70 (saturation)		-	70 (saturation)		6/5/96	RDB
Chlordane	0.0043	5	22 (saturation)		-	22 (saturation)		6/12/96	RDB
Carbon tetrachloride	12	5	0.15		2400	232 (saturation)		6/12/96	RDB

Conversion Factor calculated as: non-drinking water GAL/drinking water GAL  
Soil action level calculated as: drinking water source threatened SAL x conversion factor

**SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALS)**  
**Drinking water source threatened; annual rainfall = 400cm**  
**Tier 1 SALS directly generated using SESOIL (see text)**

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw Impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated Input soil concentration (ug/g)	T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
Benzene	.005	75	8th yr, 4th mo	9,883	49.4	7.0	1st yr, 3rd mo	806,720	2.7	8/18/95	RDB
Benzene	.005	100	10th yr, 6th mo	18,634	93.2	31.3	1st yr, 3rd mo	3,616,900	12	8/18/95	RDB
Toluene	1.0	20	4th yr, 2nd mo	13,556	13,556	400	1st yr, 6th mo	43,140,000	143	8/18/95	RDB
Ethylbenzene	0.14	5	2nd yr, 3rd mo	12,189	1,706	0.40	1st yr, 6th mo	39,752	0.13	9/5/95	RDB
Ethylbenzene	0.14	10	2nd yr, 11th mo	13,361	1,870	1.0	1st yr, 6th mo	105,484	0.35	9/5/95	RDB
Ethylbenzene	0.14	20	4th yr, 4th mo	9,591	1,343	4.45	1st yr, 6th mo	483,440	1.6	9/5/95	RDB
Ethylbenzene	0.14	30	5th yr, 8th mo	9,976	1,397	12.5	1st yr, 6th mo	1,362,010	4.5	9/5/95	RDB
Ethylbenzene	0.14	40	6th yr, 12th mo	8,609	1,205	27.2	1st yr, 6th mo	2,973,600	9.9	9/5/95	RDB
Ethylbenzene	0.14	50	8th yr, 3rd mo	12,656	1,772	53	1st yr, 6th mo	5,782,200	19	9/5/95	RDB
Ethylbenzene	0.14	75	11th yr, 6th mo	18,885	2,644	220	1st yr, 6th mo	24,104,000	80	9/5/95	RDB
Ethylbenzene	0.14	100	14th yr, 5th mo	10,818	1,515	> saturation at T-1	1st yr, 6th mo	59,595,000	200 (saturation)	9/5/95	RDB
Xylene	10	5	2nd yr, 2nd mo	14,013	140,130	21.5	1st yr, 6th mo	2,433,100	8.1	9/4/95	RDB
Xylene	10	10	2nd yr, 8th mo	9,055	9,055	46	1st yr, 6th mo	5,551,800	18	9/4/95	RDB
Xylene	10	20	3rd yr, 9th mo	7,882	7,882	> saturation at T-1	1st yr, 6th mo	17,630,400	59 (saturation)	9/4/95	RDB
Benzo(a)pyrene	0.0002	5	>20 years				<1m after 20 yrs	1,020,000	3.4 (saturation)	9/4/95	RDB
Acenaphthene	0.32	5	>20 years				7th yr, 6th mo	5,400,000	18 (saturation)	9/4/95	RDB
Fluoranthene	0.013	5	>20 years				<1m after 20yrs	3,300,000	11 (saturation)	9/4/95	RDB
Naphthalene	0.24	5	4th yr, 8th mo	9,007	2,162	> saturation at T-1	2nd yr, 10th mo	12,300,000	41 (saturation)	9/5/95	RDB
PCE	0.005	5	4th yr, 3rd mo	12,189	61.0	0.25	2nd yr, 3rd mo	11,326	0.04	9/4/95	RDB
PCE	0.005	10	6th yr, 1st mo	10,205	51.0	1.13	2nd yr, 4th mo	43,640	0.15	9/4/95	RDB
PCE	0.005	20	9th yr, 8th mo	9,551	47.8	8.1	2nd yr, 5th mo	263,145	0.88	9/4/95	RDB
PCE	0.005	30	13th yr, 3rd mo	12,044	60.2	29	2nd yr, 6th mo	782,750	2.6	9/4/95	RDB
PCE	0.005	40	16th yr, 8th mo	9,995	50.0	69	2nd yr, 6th mo	1,864,290	6.2	9/4/95	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALS)

Drinking water source threatened; annual rainfall = 400cm

Tier 1 SALS directly generated using SESOIL (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw Impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated		T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
						Input soil concentration (ug/g)	Target monthly flux (ug)					
1,1 DCE	0.046	5	9th yr, 7th mo	18,913	870	> saturation at T-1	> saturation at T-1	2nd yr, 8th mo	145,497,000	490 (saturation)	9/5/95	RDB
Vinyl Chloride	0.002	5	>20 years			> saturation at T-1	> saturation at T-1	8th yr, 6th mo	1,768,500,000	5,900 (saturation)	9/5/95	RDB
TCE	0.005	5	2nd yr, 1st mo	10,477	52.4	0.010	52.4	1st yr, 4th mo	1,306	0.004	9/14/95	RDB
TCE	0.005	10	2nd yr, 8th mo	9,055	45.3	0.024	45.3	1st yr, 5th mo	2,343	0.008	9/14/95	RDB
TCE	0.005	20	4th yr, 3rd mo	12,013	60.1	0.105	60.1	1st yr, 5th mo	10,460	0.03	9/14/95	RDB
TCE	0.005	30	5th yr, 8th mo	9,976	49.9	0.25	49.9	1st yr, 5th mo	24,950	0.08	9/15/95	RDB
TCE	0.005	40	7th yr, 1st mo	10,248	51.2	0.464	51.2	1st yr, 5th mo	46,261	0.15	9/14/95	RDB
TCE	0.005	50	8th yr, 6th mo	19,477	97.4	0.815	97.4	1st yr, 5th mo	81,082	0.27	9/14/95	RDB
TCE	0.005	75	11th yr, 12th mo	8,858	44.3	2.07	44.3	1st yr, 5th mo	205,490	0.68	9/14/95	RDB
TCE	0.005	100	15th yr, 3rd mo	12,438	62.2	4.46	62.2	1st yr, 5th mo	441,620	1.5	9/14/95	RDB
1,1,1 TCA	0.20	5	1st yr, 9th mo	7,404	1480	0.100	1480	1st yr, 4th mo	19,223	0.06	9/14/95	RDB
1,1,1 TCA	0.20	10	2nd yr, 2nd mo	13,603	2721	0.187	2721	1st yr, 4th mo	38,063	0.13	9/14/95	RDB
1,1,1 TCA	0.20	20	2nd yr, 9th mo	7,882	1576	0.314	1576	1st yr, 4th mo	65,590	0.22	9/14/95	RDB
1,1,1 TCA	0.20	30	3rd yr, 6th mo	19,904	3981	0.623	3981	1st yr, 4th mo	131,211	0.44	9/14/95	RDB
1,1,1 TCA	0.20	40	4th yr, 1st mo	10,248	2050	0.821	2050	1st yr, 4th mo	173,370	0.58	9/14/95	RDB
1,1,1 TCA	0.20	50	4th yr, 8th mo	10,386	2077	1.19	2077	1st yr, 4th mo	250,570	0.83	9/14/95	RDB
1,1,1 TCA	0.20	75	6th yr, 3rd mo	12,037	2407	2.47	2407	1st yr, 4th mo	520,750	1.7	9/14/95	RDB
1,1,1 TCA	0.20	100	7th yr, 7th mo	19,087	3817	4.39	3817	1st yr, 4th mo	927,270	3.1	9/14/95	RDB
Acetone	0.61	5	1st yr, 3rd mo	12,189	7,435	0.313	7,435	1st yr, 1st mo	18,270.9	0.061	2/24/96	RDB
Chlorobenzene	0.10	5	1st yr, 10th mo	11,368	1,137	0.073	1,137	1st yr, 4th mo	13,511	0.045	2/24/96	RDB
Chloroform	9.6	5	1st yr, 6th mo	20,477	3.27	0.0004	3.27	1st yr, 2nd mo	28.7	0.0001	2/24/96	RDB
4,4 DDD	0.6	5	> 20 years			> saturation at T-1	> saturation at T-1	<1m after 20yrs	37,260,687	124 (saturation)	2/24/96	RDB
4,4 DDE	0.014	5	> 20 years			> saturation at T-1	> saturation at T-1	<1m after 20yrs	158,400,528	528 (saturation)	2/24/96	RDB
4,4 DDT	0.000001	5	> 20 years			> saturation at T-1	> saturation at T-1	<1m after 20yrs	244,718	0.82 (saturation)	2/24/96	RDB
Di-n-octyl phthalate	0.73	5	> 20 years			> saturation at T-1	> saturation at T-1	<1m after 20yrs	9,152,921	31 (saturation)	2/24/96	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)

**SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALS)**  
**Drinking water source threatened; annual rainfall = 400cm**  
**Tier 1 SALS directly generated using SESOIL (see text)**

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated input soil concentration (ug/g)	T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
Ethylene glycol	73,000	5	1st yr, 2nd mo	14,013	1E+09	> saturation at T-1	1st yr, 1st mo	5,444,000,000	18,147 (saturation)	2/24/96	RDB
Methylene chloride	0.0043	5	1st yr, 6th mo	10,567	45.4	0.005	1st yr, 1st mo	719.7	0.0024	2/24/96	RDB
2,3,7,8 TCDD	0.003	5	> 20 years			> saturation at T-1	<1m after 20yrs	21,000,000	70 (saturation)	6/5/96	RDB
Chlordane	0.002	5	> 20 yrs				:1.5m after 20yn	6,559,161	22 (saturation)	6/12/96	RDB
Carbon tetrachloride	0.005	5	2nd yr, 10th mo	11,368	57	0.14	1st yr, 6th mo	7,168	0.024	6/12/96	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)



# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source not threatened; annual rainfall = 400cm

Tier 1 SALs directly generated using SESOIL (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	T-2 Time max gw Impact	GW recharge (ml)	Target monthly flux (ug)	Calibrated Input soil concentration (ug/g)	T-1 Time scenario begins	Contaminant mass at T-1 (ug)	Contaminant concentration at T-1 (ug/g, Tier 1 SAL)	Date modeled	Modeled by
Benzene	1.7	5	1st yr, 8th mo	9,007	15,312	1.94	1st yr, 3rd mo	192,760	0.64	8/18/95	RDB
Benzene	1.7	10	2nd yr, 2nd mo	13,603	23,125	5.3	1st yr, 3rd mo	571,100	1.9	8/18/95	RDB
Benzene	1.7	20	3rd yr, 2nd mo	13,556	23,045	25.9	1st yr, 3rd mo	2,917,800	9.7	8/18/95	RDB
Benzene	1.7	30	4th yr, 1st mo	10,228	17,388	73	1st yr, 3rd mo	8,347,600	28	8/18/95	RDB
Benzene	1.7	40	4th yr, 12th mo	8,609	14,635	180	1st yr, 3rd mo	20,635,000	69	8/18/95	RDB
Benzene	1.7	50	5th yr, 11th mo	12,594	21,410	349	1st yr, 3rd mo	42,635,000	140	8/18/95	RDB
Toluene	2.1	5	2nd yr, 3rd mo	12,189	25,597	26.6	1st yr, 6th mo	1,613,900	5.4	8/18/95	RDB
Toluene	2.1	10	2nd yr, 11th mo	13,361	28,058	129	1st yr, 6th mo	8,246,200	28	8/18/95	RDB
Toluene	2.1	20	4th yr, 2nd mo	13,556	28,486	> saturation at T-1	1st yr, 6th mo	50,389,000	170 (saturation)	8/18/95	RDB

Tier 1 soil action level (SAL) calculated as: contaminant mass at T-1/mass of soil (see text)

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source not threatened; annual rainfall = 400cm

Tier 1 SALs indirectly generated using SALs generated for drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source threatened (mg/kg)	Conversion factor	Tier 1 SAL for drinking-water source not threatened (mg/kg)	Date modeled	Modeled by
Benzene	1.7	75	2.7	340	210 (saturation)	8/18/95	RDB
Toluene	2.1	20	143	2.1	170 (saturation)	8/18/95	RDB
Ethylbenzene	0.14	5	0.13	1	0.13	9/5/95	RDB
Ethylbenzene	0.14	10	0.35	1	0.35	9/5/95	RDB
Ethylbenzene	0.14	20	1.6	1	1.6	9/5/95	RDB
Ethylbenzene	0.14	30	4.5	1	4.5	9/5/95	RDB
Ethylbenzene	0.14	40	9.9	1	9.9	9/5/95	RDB
Ethylbenzene	0.14	50	19	1	19	9/5/95	RDB
Ethylbenzene	0.14	75	80	1	80	9/5/95	RDB
Ethylbenzene	0.14	100	200 (saturation)	-	200 (saturation)	9/5/95	RDB
Xylene	10	5	8.1	1	8.1	8/23/95	RDB
Xylene	10	10	18	1	18	8/23/95	RDB
Xylene	10	20	59 (saturation)	-	59 (saturation)	8/23/95	RDB
Benzo(a)pyrene	0.0002	5	3.4 (saturation)	-	3.4 (saturation)	9/4/95	RDB
Acenaphthene	0.32	5	18 (saturation)	-	18 (saturation)	9/4/95	RDB
Fluoranthene	0.013	5	11 (saturation)	-	11 (saturation)	9/4/95	RDB
Naphthalene	0.77	5	41 (saturation)	-	41 (saturation)	9/4/95	RDB
PCE	0.145	5	0.04	29	1.2	9/4/95	RDB
PCE	0.145	10	0.15	29	4.4	9/4/95	RDB
PCE	0.145	20	0.88	29	26	9/4/95	RDB
PCE	0.145	30	2.6	29	75	9/4/95	RDB
PCE	0.145	40	6.2	29	130 (saturation)	9/4/95	RDB

Conversion Factor calculated as: non-drinking water GAL/drinking water GAL  
Soil action level calculated as: drinking water source threatened SAL x conversion factor

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source not threatened; annual rainfall = 400cm

Tier 1 SALs indirectly generated using SALs generated for drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source threatened (mg/kg)	Conversion factor	Tier 1 SAL for drinking-water source not threatened (mg/kg)	Date modeled	Modeled by
1,1 DCE	3.9	5	490 (saturation)	-	490 (saturation)	9/3/95	RDB
Vinyl Chloride	0.002	5	5,900 (saturation)	-	5,900 (saturation)	9/4/95	RDB
TCE	0.70	5	0.004	140	0.56	9/14/95	RDB
TCE	0.70	10	0.008	140	1.1	9/14/95	RDB
TCE	0.70	20	0.03	140	4.9	9/14/95	RDB
TCE	0.70	30	0.08	140	12	9/14/95	RDB
TCE	0.70	40	0.15	140	22	9/14/95	RDB
TCE	0.70	50	0.27	140	38	9/14/95	RDB
TCE	0.70	75	0.68	140	95	9/14/95	RDB
TCE	0.70	100	1.5	140	210 (saturation)	9/14/95	RDB
1,1,1 TCA	6.0	5	0.06	30	1.9	9/14/95	RDB
1,1,1 TCA	6.0	10	0.13	30	3.8	9/14/95	RDB
1,1,1 TCA	6.0	20	0.22	30	6.6	9/14/95	RDB
1,1,1 TCA	6.0	30	0.44	30	13	9/14/95	RDB
1,1,1 TCA	6.0	40	0.58	30	17	9/14/95	RDB
1,1,1 TCA	6.0	50	0.83	30	25	9/14/95	RDB
1,1,1 TCA	6.0	75	1.7	30	52	9/14/95	RDB
1,1,1 TCA	6.0	100	3.1	30	93	9/14/95	RDB
Acetone	0.61	5	0.061	1	0.061	2/24/96	RDB
Chlorobenzene	0.10	5	0.045	1	0.045	2/24/96	RDB
Chloroform	9.6	5	0.0001	6,000	6.0	2/24/96	RDB
4,4 DDD	0.6	5	124 (saturation)	-	124 (saturation)	2/24/96	RDB

Conversion Factor calculated as: non-drinking water GAL/drinking water GAL  
 Soil action level calculated as: drinking water source threatened SAL x conversion factor

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source not threatened; annual rainfall = 400cm

Tier 1 SALs indirectly generated using SALs generated for drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source threatened (mg/kg)	Conversion factor	Tier 1 SAL for drinking-water source not threatened (mg/kg)	Date modeled	Modeled by
4,4 DDE	0.014	5	528 (saturation)	-	528 (saturation)	2/24/96	RDB
4,4 DDT	0.000001	5	0.82 (saturation)	-	0.82 (saturation)	2/24/96	RDB
Di-n-octyl phthalate	0.73	5	31 (saturation)	-	31 (saturation)	2/24/96	RDB
Ethylene glycol	73,000	5	18,147 (saturation)	-	18,147 (saturation)	2/24/96	RDB
Methylene chloride	0.0043	5	0.0024	1	0.0024	2/24/96	RDB
2,3,7,8 TCDD	0.003	5	70 (saturation)	-	70 (saturation)	6/5/96	RDB
Chlordane	0.0043	5	22 (saturation)	-	22 (saturation)	6/12/96	RDB
Carbon tetrachloride	12	5	0.024	2400	58	6/12/96	RDB

Conversion Factor calculated as: non-drinking water GAL/drinking water GAL  
Soil action level calculated as: drinking water source threatened SAL x conversion factor

# SUPPORTING DATA FOR TIER 1 SOIL ACTION LEVELS (SALs)

Drinking water source threatened; annual rainfall = 400cm

Tier 1 SALs Indirectly generated using SALs generated for non-drinking water sites (see text)

Contaminant	Target GAL (mg/l)	Depth to gw (m)	Tier 1 SAL for drinking-water source not threatened (mg/kg)		Conversion factor	Tier 1 SAL for drinking-water source threatened (mg/kg)		Date modeled	Modeled by
Benzene	0.005	5	0.64	0.00294	0.00294	0.002	0.002	8/18/95	RDB
Benzene	0.005	10	1.9	0.00294	0.00294	0.006	0.006	8/18/95	RDB
Benzene	0.005	20	9.7	0.00294	0.00294	0.03	0.03	8/18/95	RDB
Benzene	0.005	30	28	0.00294	0.00294	0.08	0.08	8/18/95	RDB
Benzene	0.005	40	69	0.00294	0.00294	0.20	0.20	8/18/95	RDB
Benzene	0.005	50	142	0.00294	0.00294	0.42	0.42	8/18/95	RDB
Toluene	1.0	5	5.4	0.476	0.476	2.6	2.6	8/18/95	RDB
Toluene	1.0	10	28	0.476	0.476	13	13	8/18/95	RDB

Conversion Factor calculated as: drinking water GAL/ non-drinking water GAL  
Soil action level calculated as: non-drinking water source threatened SAL x conversion factor